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CORRELATION OF SILURIAN FORMATIONS IN SOUTHWESTERN OHIO, SOUTHEASTERN INDIANA, KENTUCKY, AND WESTERN TENNESSEE

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FORMATIONS

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A. PREFACE

The following paper is a study of those Silurian formations which are in more or less direct contact with the Cincinnati anticline. Special attention is given to Silurian formations in southwestern Ohio, southeastern Indiana, both eastern and western Kentucky, and western Tennessee. In this area some of the constituent formations have a wide distribution; others are of more limited extent. Difficulties in correlation arise owing to changes in lithology and of faunas. An attempt is made to indicate those areas in which constancy of lithology and of faunal content permits the tracing of formations with confidence, and also to indicate those intermediate areas where, at present, the geographical connuity of these formations appears interrupted, so that correlation across these areas appears uncertain. Attention is called to the necessity for detailed study of these more doubtful areas.

Problems of this sort are not new. It has long been known that the Silurian of the northern half of Indiana differs both lithologically and faunally from that of its southern half, so that Cumings and Shrock have found it convenient to propose distinct formation names to express the results of their studies in the northern part of that state. In a similar manner, Chamberlin found that the Silurian of that part of Wisconsin which lies north of the Milwaukee area was distinct lithologically and faunally from that south of this area and including both southeastern Wisconsin and northeastern Illinois; and Ehlers has introduced a series of new formation names to express the result of his studies in northern Michigan. It will be interesting to learn how far eastward it will be possible to trace the Silurian formations of the northern peninsula of Michigan and how far westward those characteristic of southern Ontario and the eastern half of Manitoulin island.

It is obvious that in some areas the solution of such problems is prevented by inadequate exposures. Either these exposures are too few in number, or they are not of sufficient vertical range, or the component faunales are not diagnostic. In the thicker formations the component faunules frequently have not been determined and the order of sequence of these faunules is unknown.

Hence, in these instances, the sequence of species in the doubtful areas has no significance to the observer.

In many cases the correlation of faunas in adjacent areas is based on the presence of only one or two species. It becomes a matter of great importance then as to the value of the species selected as a diagnostic element of the fauna. It is certain that the significance of correlations would be greatly increased if authors were to state definitely upon what basis each individual correlation rests. This would enable other students of the same problem to determine whether their own studies lead to similar results.

It is obvious, that in our present state of knowledge, the so-called long-ranging species have little diagnostic value, though a detailed study of their zonal variations might lead to a different result. Moreover, those not readily identified, except under excellent conditions of preservation, may lead to a misinterpretation of the section. Every investigator learns from long experience which species can be most readily identified, have the widest distribution, and stick most closely to a definite horizon. It is proper for him to avail himself of such information, but it also is proper that the basis of his conclusions be stated adequately.

Formerly it was customary to correlate horizons by stating the percentage of species in one formation listed also from two or three other formations in other areas. However, considering the latitude allowed by some investigators in the identification of such species, these identifications often are of subgeneric, rather than of specific value. This is true especially of lists collated from different publications by different authors.

Under these circumstances it seems preferable to base correlations on a close study of species which are readily identified, and which experience has shown to be diagnostic of definite horizons, at least within the limited area under investigation.

B. MEDINAN

1. *Brassfield limestone; general remarks*

The limestone at the base of the Silurian in southwestern Ohio was identified by Orton as *Clinton*. When its difference faunally

from the Clinton of New York was recognized it often was called the *Ohio Clinton*. Later, in 1906, it was termed the *Brassfield* limestone by Foerste, the typical exposure being along the Louisville and Atlantic Railroad, between Brassfield and Panola, in Madison County in east-central Kentucky. Here its thickness is 21 feet, presenting the following section in descending order:

	feet
Ferruginous limestone	1.5
Horizon with large crinoid beads and *Whitfieldella subquadrata*.	
Irregularly bedded limestone with very little clay	2
Clay forming from one-half to three-fourths of the section, interbedded with thin limestone	3.3
Limestone, irregularly bedded, with thin clay partings	8.2
Very massive bluish limestone, apparently unfossiliferous	6

This section at Brassfield represents the maximum thickness of the Brassfield limestone in east-central Kentucky from as far south as Stanford to as far north as Owingsville. From Owingsville northward the thickness of the Brassfield limestone gradually increases to 40 feet, and locally even to 50 feet, in Adams and Highland counties, Ohio, and then gradually diminishes northwestward to 28 feet at Ludlow Falls, to 22 feet at Lewisburg, Ohio, and to 14 feet at the Elkhorn Falls, 4 miles south of Richmond, Indiana. Thence the Brassfield continues to diminish in thickness, but in a southwestward direction, until it is entirely absent in an area including adjacent parts of Ripley, Jennings, and Decatur counties in Indiana. Between Batesville and the most southern outcrops of the Brassfield limestone in Indiana, at Charlestown Landing, the thickness of this limestone usually does not exceed 5 feet. The Brassfield limestone remains thin in Trimble and Oldham counties, Kentucky, and then increases in thickness in Nelson and Marion counties southward, south of which there are no exposures on the western side of the Cincinnati anticline until the exposures in northern Tennessee are reached. These thicken southwestward from 3 feet east of Bledsoe to 33 feet in the area between Franklin and Centreville, Tennessee.

Since there are no outcrops of Brassfield limestone between Maysville and Madison in north-central Kentucky, nor in the adjacent parts of Indiana and Ohio, for an east and west width

of 90 miles, nothing can be said with confidence regarding the presence or absence of the Brassfield limestone in early Silurian times within this area, but the facts known at present permit the idea that the Brassfield originally may have extended across this intermediate area, thinning out gradually westward. Such an extension is suggested by the occurrence of the Brassfield limestone on the top of Jeptha Knob, 6 miles southeast of Shelbyville, Kentucky, though this single occurrence is by no means conclusive.

Among other features observed in the general area here under discussion is the presence of large crinoid columnals, from one-half inch to almost an inch in diameter, at the top of the Brassfield limestone on the eastern side of the Cincinnati anticline from as far north as the Soldiers Home west of Dayton, Ohio, to as far south as Stanford, Kentucky, reappearing at the outcrops on the Cumberland River about 15 miles west of Burnside, Kentucky.

This crinoid bead horizon usually is overlaid by a thin zone containing *Whitfieldella subquadrata*, in the area south of Owingsville, Kentucky, while farther north, in Adams County, Ohio, *Whitfieldella quadrangularis* occupies about the same zone. The layers containing these Whitfieldellas and the underlying large crinoid beads often are coarse grained and sometimes cross-bedded, and their upper surfaces or those of the immediately overlying layers are wave-marked, the crests of these so-called wave-marks often being nearly an inch high and from 2 to 3 feet apart. These wave-marks are known from as far south as Irvine, Kentucky, to as far north as Soldiers Home, west of Dayton, Ohio, and thence as far west as the Brassfield exposure about 2 miles south of Eaton in the same state.

Moreover, the upper layers of the Brassfield formation, especially those above the Crinoid bead and Whitfieldella horizons, frequently are ferruginous, the ferruginous phase of the Brassfield extending northward from the vicinity of Kiddville, northwest of Clay City, Kentucky, as far as the exposure on Todd Fork, about 2 miles north of Wilmington, Ohio. Locally this ferruginous zone formerly was worked as an iron ore, hematite, especially at Rose Run, 4 miles east of Owingsville, Kentucky.

It possibily is significant that on the western side of the Cincinnati anticline the Brassfield limestone often has a salmon brown color in the area centering at Madison, Indiana, layers having this color being known as far north as Laurel in that state and as far south as Salt River, 20 miles southeast of Louisville, Kentucky. This salmon brown color apparently is due to a slightly greater ferruginous content in the Brassfield limestone of the area indicated.

On the east side of the Cincinnati anticline the lower part of the Brassfield is cherty in the area between Sharpsville at the southern margin of Clinton county, Ohio, and Owingsville, Kentucky. West of the anticline there is a cherty phase of the Brassfield in the vicinity of Bardstown, while an apparently siliceous phase of the Brassfield continues northward through Jefferson county in southern Indiana.

Pebbles are not uncommon at various horizons in the Brassfield formation in the area extending between Sharpsville, Ohio, as far south as Belfast in the same state. A good exposure occurs on Elk Run, about 2 miles east of Belfast. Here the top of the Brassfield is ferruginous. Below, there are wave-marks about 2 inches in height and 28 inches apart from crest to crest. These wave-marks form the upper surface of a conglomerate layer in which many pebbles range from 4 to 8 inches in length, some reaching 12 inches, the conglomerate being intraformational in origin, the pebbles being derived from lower horizons in the Brassfield, and containing Brassfield fossils in consequence.

Pebbles occur in the Brassfield also on the western side of the Cincinnati anticline, chiefly in Ripley county. Here they usually are not more than one inch long, though pebbles 2 inches long are recorded from several localities. Those 3 inches long are rare, and one flat piece of included rock, 6 to 8 inches long, was found at one locality. Most of these pebbles consist of a very fine-grained white limestone, evidently derived from the very top of the Ordovician as exposed in this part of Indiana. The most common fossil in this white limestone, where exposed directly beneath the Brassfield, is *Tetradium*, but this rarely appears in the pebbles. Not infrequently, this white limestone, where occurring immediately beneath the Brassfield, is cracked and the

salmon brown Brassfield calcareous particles, before solidifying to rock, filtered down into the narrow cracks. The pebbles frequently are angular. Some of these pebbles consist of detrital material of Ordovician age, including *Rafinesquina alternata* and other fossils characteristic of the underlying Richmond.

Such observations suggest the possibility of an east and west connection of the Brassfield formation across the Cincinnati anticline in areas considerable farther south than their present areas of outcrop on the crest of this anticline in Montgomery and Preble counties, Ohio.

The extension of the Brassfield across the crest of the anticline in central Kentucky is suggested also by the inlier of this formation on Scrub Grass Creek, 3 miles southwest of Mitchellsburg, in that state discussed in section 33 of this paper.

C. CLINTON OF EASTERN KENTUCKY AND SOUTHERN OHIO

2. *Crab Orchard group*

In east-central Kentucky the Brassfield limestone is overlaid by a series of strata consisting chiefly of unfossiliferous clay shale, but including in its lower half, at two horizons, also more or less fossiliferous interbedded limestone layers. This clay shale series with its interbedded limestone horizons was called the *Crab Orchard* group by W. M. Linney in 1882, in his Report on the Geology of Lincoln County, published by the Geological Survey of Kentucky. In 1906 the lower one of these limestone horizons was called the *Oldham* limestone and the upper limestone horizon was called the *Waco* limestone, both by Foerste in his report on the Silurian, Devonian, and Irvine formations of East-Central Kentucky, published by the same survey. In the same report the name *Alger* formation was proposed for those clays in the Crab Orchard sequence which lie above the Oldham limestone. This formation was named after Alger, a station on the railroad between Panola and Irvine about a mile east of the line between Estill and Madison counties. The lower part of this Alger formation contains the Waco limestone horizon in east-central Kentucky, but farther north, in Bath, Fleming, and Lewis counties,

where the Waco limestone no longer can be detected, the Alger formation consists of a continuous series of unfossiliferous clay shales. In the eastern part of Bath county this Alger clay shale rests on the limestone there identified as Oldham. In Lewis county, however, it rests on the *Dayton* limestone, a formation continuing through southwestern Ohio to the western part of Preble county, and there identified stratigraphically with the Laurel limestone of southeastern Indiana.

In east-central Kentucky the Alger formation is overlaid by middle Devonian limestone. This limestone has not been traced north of Bath county. In Lewis county, the unfossiliferous Alger clay shale is overlaid by the *Ribolt* shale which differs from the Alger shale in being interbedded with numerous thin layers of more or less fossiliferous indurated shale. This Ribolt shale, in turn, is overlaid by the *Bisher* formation, consisting chiefly of an argillaceous or arenaceous limestone. At most localities within Lewis county the Bisher is overlaid directly by the Ohio Black shale, but on the Ohio River, at Vanceburg, the Cayugan Greenfield dolomite intervenes.

The total thickness of the Crab Orchard group, in east-central Kentucky, equals 100 feet at Crab Orchard and 114 feet north of Irvine. Thence it decreases to 80 feet about 8 miles west of Indian Fields, and to 70 feet two miles west of Preston, near the western margin of Bath county, in the area west of Owingsville.

In Lewis county, Kentucky, the total thickness of the Alger-Ribolt clay shale series is fully 100 feet. The type exposure of the Ribolt shale is at Ribolt, 10 miles west of Vanceburg, within this county. At West Union and Peebles in Adams county, Ohio, this Alger-Ribolt section is 150 feet thick. At Hillsboro, Ohio, this Alger-Ribolt section equals only 62 feet. In Lewis and Adams counties the Ribolt forms about 30 feet of the total section. At Hillsboro the thickness of the Ribolt is estimated at 20 feet.

North of Hillsboro no trace of the fossiliferous Ribolt shale has been detected. The argillaceous strata exposed in the creek crossed by the railroad about a mile east of Leesburg, and those exposed along the creek a short distance west of Port William possibly correspond to the Bisher formation of more southern areas.

On Massie Creek, a short distance west of Cedarville, Ohio, the Euphemia dolomite is underlaid by the *Massie* clay, carrying a Waldron fauna. At the Bryan Farm State Park, 5 miles northwest of Cedarville and 2 or 3 miles south of Yellow Springs, the following section is exposed, in descending order:

	feet
Cedarville dolomite	6
Springfield dolomite	11.7
Euphemia dolomite	6.5
Massie clay	5.5
Laurel limestone	5.7
Osgood or Alger clay	40
Dayton limestone	5
Brassfield limestone	Top

In this section the Osgood or Alger clay is well exposed only along its upper part, the lower part of this clay section and the upper part of the underlying Dayton limestone being more or less covered by talus. The identification of the clay section as Alger or Osgood is made chiefly on stratigraphic grounds, no diagnostic fossils being present.

West of the Miami River, near Covington and Ludlow Falls, in Miami county, and near Lewisburg and New Paris in Preble county, Ohio, the indurated clay there identified as Osgood is only about 4 feet thick. In the area west of Laurel, in Franklin county, Indiana, this four foot clay layer appears to be represented by the one foot indurated clay or soapstone at the top of the section there identified as Osgood.

Stratigraphically, therefore, it seems possible to trace the Alger clay of southern Ohio into the clay at the top of the Osgood of southeastern Indiana. Paleontologically, however, such a correlation does not seem warranted.

Judging from their faunas, the Osgood fauna appears to belong higher in the Upper Clinton than the Ribolt fauna, and the Alger clay, although possibly of about the same age as the Ribolt, is at least a little older. Of course, their difference in faunal content may be explained in part by their difference in origin, the Osgood fauna having invaded from the south, while the Ribolt fauna has its affiliations in the east. Both the Osgood and the Bisher may be older than the typical Rochester of New York.

The real difficulty in correlating the Alger with any formation in Indiana is due to changes in lithological appearance of the clay sections in areas intermediate between the typical Alger clay and the typical Osgood, the attempt to trace the same clay horizon through these intermediate areas being accompanied by a series of assumptions which vitiate the reliability of the final result.

3. *Oldham limestone*

The lower one of the two limestone horizons in the Crab Orchard group in east-central Kentucky occurs usually about 4 or 5 feet above the Brassfield limestone. This lower limestone was called the Oldham limestone by Foerste in 1906, and at the same time that portion of the clay section which intervenes between the base of the Oldham limestone and the top of the underlying Brassfield limestone was called the Plum Creek clay. The clay is unfossiliferous and usually is sharply separable from the two limestones mentioned but sometimes grades into the latter.

The Oldham limestone usually varies between 10 and 11 feet in thickness. The characteristic fossil *Stricklandinia norwoodi* occurs at the top of this limestone in the area intervening between Brassfield, Indian Fields, Clay City, and Irvine, wherever this limestone is exposed. Southwest of Berea, Kentucky, the identification of the Oldham limestone often is attended with difficulties owing to the absence of the *Stricklandinia,* and also owing to gradual changes in the lithological character of the strata. The Oldham limestone has been traced lithologically as far north as the Rose Run Iron Mine area, 4 miles east of Owingsville. Here the Oldham limestone is separated from the underlying Brassfield by the very characteristic Plum Creek clay. Farther north however thin limestone layers are interbedded with the Plum Creek clay in sufficient number to make the discrimination between the Oldham and the Plum Creek members of the Crab Orchard group increasingly more difficult. Apparently the Oldham limestone disappears entirely before reaching Fleming county, Kentucky. This undoubtedly is true if the *Stricklandinia norwoodi* horizon in east-central Kentucky is equivalent to the horizon at which this species occurs in the Clinton section at Birmingham, Ala-

bama, and if the *Pentamerus* horizon in the Dayton limestone of Adams county, Ohio, corresponds to that *Pentamerus* horizon in the Birmingham area which there overlies the *Stricklandinia norwoodi* zone. (The Paleontology of Kentucky, p. 186, pl. 19, fig. 14, *1931*.)

In the character of its surface ornamentation *Stricklandinia norwoodi* Foerste closely resembles *Pentamerus corrugatus* Weller and Davidson. Jour. Geol., vol. 4, p. 171, pl. 7, figs. 4, 3, *1896*.

4. Waco limestone

In east-central Kentucky the Oldham limestone is overlaid by the Lulbegrud clay, and the latter by the Waco limestone, these names having been proposed by Foerste in 1906.

In the area between Irvine, Clay City, Indian Fields, and Brassfield the thickness of the Lulbegrud clay is between 13 and 14 feet. The solid layer of limestone, between 9 and 24 inches thick, which overlies the Lulbegrud clay and which is assumed as marking the base of the Waco limestone section, can not be traced southward with certainty beyond Berea. Near Crab Orchard the thickness of the Lulbegrud clay can not exceed 6 feet.

The solid layer of limestone at the base of the Waco section has been traced over the entire area included between the four cities mentioned above, this area being 25 miles long and 12 miles broad. No limestone with which this layer can be confused is known at any other horizon within the Crab Orchard group. Hence it has been found an important horizon marker.

The Waco limestone section includes this solid limestone layer at its base and in the Waco area, east of Moberly Station, in Madison county, totals about 10 or 11 feet. That part of the Waco section overlying the solid thick limestone consists chiefly of clay, but interbedded with numerous very thin layers of limestone, the latter often weathering to an irregular rubble. Both the limestone and the interbedded clay often is richly fossiliferous. Corals predominate. Bryozoans are fairly common. Other fossils are comparatively scarce. (The Paleontology of Kentucky, p. 187, pl. 20, *1931*.)

No specific attempt has been made as yet to trace the Waco

limestone section farther north or farther south than the area here indicated, though, if present, it should have been detected during general investigations in these more distant areas.

5. *Alger clay*

That part of the Crab Orchard clay which overlies the Waco limestone horizon is called the Estill clay, the typical exposure being northeast of Estill Springs, north of Irvine, Kentucky. Here the Estill clay is 56 feet thick. Farther southwest, in the vicinity of Crab Orchard, in the eastern part of Lincoln County, its thickness exceeds 65 feet. This Estill clay is unfossiliferous.

The fossiliferous limestone layers included in the Waco limestone can be traced as far north as Clay City in Powell County and Indian Fields in the southeastern part of Clark County. The base of this Waco limestone is formed by a layer of solid limestone varying from one to two feet in thickness, which also can be traced as far north as Clay City and Indian Fields. However, farther north, in Montgomery, Bath, Fleming, and Lewis counties, no trace of the Waco limestone has been found, unless the solid limestone layer at its base corresponds to the Dayton limestone of Lewis county, Kentucky, and of Adams, Highland, and more northern counties of Ohio, but there is no evidence, either stratigraphic or paleontologic, which warrants such a correlation at present.

The Oldham limestone may be traced by means of its characteristic fossil, *Stricklandinia norwoodi*, as far north as Clay City and Indian Fields. North of the area within which the Oldham limestone may be identified by means of its characteristic fossil it can be traced only stratigraphically. At the Rose Run Iron Mines four miles east of Owingsville, in Bath County, the wave-marked limestone at the top of the iron ore of the Brassfield section is overlaid by 8 feet of clay identified as Plum Creek clay, and the latter by 5 feet of limestone and clay identified as the lower part of the Oldham limestone. This Oldham limestone contains an ostracod identified as *Zygobolba rectangula*, a species characteristic of the middle part of the Lower Clinton at Cumberland, Maryland, and Hagan, Virginia. Further study of the

fauna at the Rose Run locality is needed before its correlation with the Oldham is accepted as established.

A section exposed a mile north of Hillsboro, in Fleming county, exposes the ferruginous limestone at the top of the Brassfield overlaid by the Plum Creek clay 6.5 feet thick, and the latter by limestone 5.4 feet thick identified as Oldham. At this locality the Plum Creek clay is interbedded with several thin limestone layers, and the Oldham limestone is interbedded with a relatively larger quantity of clay. No faunal evidence establishing the identity of this so-called Oldham limestone was found.

At Ribolt, 10 miles west of Vanceburg, in Lewis County, the limestone overlying the Brassfield limestone is separated from the latter by a relatively thin layer of clay. Here this limestone resembles lithologically the Dayton limestone of Adams, Highland and more northern counties. It also contains a similar faunal assemblage, especially in the line of corals.

In Adams and Highland counties of Ohio this Dayton limestone contains locally relatively numerous specimens of *Pentamerus peeblesensis* (The Paleontology of Kentucky, Kentucky Geological Survey, pl. 19, fig. 12, 1931).

Stratigraphically it seems possible to trace the Oldham limestone of east-central Kentucky northward into the Dayton limestone of southern Ohio. However, in the Birmingham area of north-central Alabama the *Pentamerus* horizon distinctly overlies the *Stricklandinia* zone, one of the species characterizing this lower zone being identical with the *Stricklandinia norwoodi* of the Oldham horizon of east-central Kentucky. Under these circumstances it seems more probable that the Dayton limestone is younger than the Oldham limestone.

Both, however, are overlaid by a thick series of unfossiliferous clay shale. In order to avoid as much as possible the duplication of names for approximately the same series of strata, the name Alger clay has been adopted for these unfossiliferous clay shales, whether resting on the Oldham limestone or on the Dayton limestone. Such an extension of the use of this term seems possible because in its original application, in east-central Kentucky, the term was used to include all Silurian formations occurring there

above the Oldham limestone, namely the Lulbegrud clay, Waco limestone, and Estill clay, in ascending order.

6. Ribolt clay shale

In earlier studies the term Alger clay was used in Lewis, Adams, and Highland counties to include not only the unfossiliferous clay shales overlying the Dayton limestone, but also a series of similar clay shales which are interbedded with thin indurated shales and which, on close search, frequently reveal distinct imprints of fossils. Since the age of these upper fossiliferous shales could be determined definitely as belonging to the *Mastigobolbina typus* fauna of more eastern states, where they occur in the middle part of the Upper Clinton, and since this fauna at present is unknown anywhere south of Lewis county, the name *Ribolt* shale was proposed in 1931 for these upper shales, and the name *Alger* clay shale was restricted to the underlying unfossiliferous clay shale.

The transition from the Alger into the Ribolt is not abrupt, and it is assumed that the greater part if not all of the Alger clay shale also is of Upper Clinton age.

Resting directly on the fossiliferous Ribolt shale in Lewis, Adams, and Highland counties is an argillaceous and arenaceous fossiliferous limestone which in the northern part of Adams county contains ostracods characteristic of the *Drepanellina clarki* zone in the upper part of the Upper Clinton of more eastern states. This fossiliferous limestone is the southern extension of the Bisher formation of Adams and Highland counties. It is overlaid by the southern extension of the Peebles dolomite of southern Ohio, and the latter by the outcrop of Greenfield dolomite, of Cayugan age, exposed on the river bank at Vanceburg, Kentucky. Neither the Bisher, nor the Peebles, nor the Greenfield is known at present south of Lewis county.

Since the Silurian section of Lewis county shows greater affinity with that of Adams and Highland counties, in Ohio, rather than with that of east-central Kentucky, it will be discussed more fully in connection with the Silurian of these more northern counties.

D. NIAGARAN OF SOUTHERN OHIO

7. Niagaran section at Hillsboro

In 1871 Orton published two reports in the *Report of Progress in 1870*, published by the Geological Survey of Ohio; one, on the Geology of Highland County; the other, on the Cliff Limestone of Highland and Adams Counties. On page 301 of the second report he published the following sequence for the Niagaran formations as exposed in descending order, from the summit of Lilley Hill at the eastern margin of Hillsboro to the level of Rocky Fork at Bisher dam, about a mile directly southward:

	feet
6. Hillsboro sandstone	30
5. Guelph, Cedarville or Pentamerus limestone	20
4. Blue Cliff and Shales, Springfield stone	45
3. Lower or West Union Cliff	45
2. Niagara shales	60
1. Dayton limestone	5

On Rocky Fork the Dayton limestone rests directly on the Brassfield limestone of Medinan age. The Dayton limestone, Niagara shale, and West Union Cliff belong to the Clinton division of the Niagaran. The Blue Cliff and the Pentamerus limestone belong to the Lockport division of the Niagaran. The Hillsboro sandstone at present is regarded as the basal part of the Lower Devonian.

The Niagara shales include both the unfossiliferous Alger clay shale and the overlying fossiliferous more indurate Ribolt shale.

The West Union Cliff includes the lower two thirds of the Bisher formation of Foerste, the upper third of the Bisher being formed by the shales which formed the basal part of the Blue Cliff of Orton.

The lithological characteristics of the Blue Cliff are described by Orton, on page 304, of the publication cited above, as follows:

Blue shales, alternating with beds of argillaceous limestone, constitute its lower portions—its upper are heavy-bedded limestones, blue in color, semicrystalline in structure, and charged with fossil corals. The rocks of the upper cliff are frequently

used as building stones, the higher beds occurring in massive courses, which are well adapted to the purposes of masonry.

Regarding the shale forming the lower part of the Blue Cliff, Orton stated on page 275 of the publication cited that "the existence of from 5 to 15 feet of blue shale at the bottom of the upper cliff can be regarded as nearly constant."

This shale is included by Foerste in his Bisher formation since, in the Lilley Hill section, the fauna characteristic of the Lilley formation is inaugurated in the immediately overlying more massive beds of Orton's Blue Cliff. The section on Lilley Hill is regarded as typical for the Niagaran, in agreement with the views held by Orton. Unfortunately Orton never described any outcrop of his West Union Cliff from any area in the vicinity of West Union, beyond the statement, on page 274 of the publication cited, that the West Union Cliff is Dr. Locke's "Cliff limestone" of Adams county—to which he (Dr. Locke) assigns a thickness of 89 feet at West Union. West Union, 27 miles south of Hillsboro, provided an excellent *name* for Orton's West Union Cliff, but not an excellent section. Unfortunately, the exposures at West Union do not include either the Lilley or the Peebles formation, so that they are not well adapted for bringing out either the lithological or the paleontological contrasts between these formations and the underlying Bisher; while the exposures on Lilley Hill are ideal for this purpose.

In areas north of Adams and Highland counties, Orton identified as West Union Cliff the basal part of the Durbin group of Niagaran rocks, later given the distinctive name of Euphemia dolomite by Foerste. This was done by Orton in his report on the geology of Clarke county in 1873 (Geological Survey of Ohio, vol. 1, pt. 1, p. 467), and in his report on Greene county in 1874 (Geological Survey of Ohio, vol. 2, pt. 1, p. 670). In the second of these publications Orton refers to an elongate form of *Atrypa reticularis,* later described by Foerste as *Atrypa reticularis elongata* (Ohio Jour. Sci., vol. 19, p. 380, pl. 16, figs. 4 A–C, 1919), as diagnostic of the West Union Cliff horizon. However, this form does not occur in the Euphemia dolomite. The West Union Cliff or Bisher is of Clinton age, while the Euphemia belongs to the

Lockport division of the Niagaran, and their faunas are very distinct.

The correlation of the Blue Cliff on Lilley Hill, at Hillsboro, Ohio, with the Springfield stone of Clarke, Greene, and more western counties in that state evidently was based on its usefulness as a flagstone, which is about the only feature held in common. The *Pentamerus* so abundant in the typical Springfield dolomite farther north does not occur in the Blue Cliff of the Hillsboro area. The Lilley formation of Foerste includes that part of the Blue Cliff of Orton which lies above the basal shale of the Blue Cliff.

The small thickness of only 20 feet assigned to the Pentamerus limestone on Lilley Hill can be explained only by assuming that in Orton's time the Pentamerus horizon at the base of the Peebles formation, as exposed in the Zink or Corporation quarry on the southern side of the pike to Marshall, was not exposed in a manner to attract attention to its fossil content. In Orton's day the term Racine had not come into general use as a stratigraphic unit, distinguishable from the overlying Guelph. Hence the Pentamerus limestone on Lilley Hill was assigned to both the Guelph and the Cedarville. The typical Cedarville of Greene, Clarke, and more western counties in Ohio, however, much more closely resembles the Racine of southeastern Wisconsin and adjacent Illinois than the Guelph of southern Ontario and northern Ohio, while the upper and more characteristic part of the Peebles limestone, with its inclusion of *Megalomus* and *Trimerella,* more closely resembles the Guelph of the areas already indicated. It is possible that the lower part of the Peebles dolomite may contain elements of the Cedarville fauna farther north but search for such Cedarville elements has been fruitless so far.

Apparent interbedding between the Hillsboro sandstone and the underlying Pentamerus limestone in Highland and Adams counties led Orton to regard this sandstone as of Niagaran age. However, the studies by Carman and Schillhahn (Jour. of Geol., vol. 38, pp. 246–261, 1930) have shown that the bedded Hillsboro sandstone rests on either the Peebles or the Greenfield dolomite, the supposed interbedded sandstones in the underlying Niagaran

representing merely fillings of cavities in these underlying dolomites by sands of later age. This Hillsboro sandstone, therefore, may represent the basal deposits of Lower Devonian age within the limits of Highland and Adams counties, and may be of about the same age as the Sylvania sandstone in northern Ohio, or even younger.

With these things in mind the Niagaran section at Hillsboro, Ohio, in descending order, is as follows:

Peebles dolomite
Lilley formation
Bisher Formation
Ribolt shale
Alger clay shale
Dayton limestone

This, moreover, is the Niagaran section for all of Highland county south of Hillsboro, and for Adams county, Ohio, and for Lewis county, in northern Kentucky. Of the overlying Cuyahogan, only the basal member, known as the Greenfield dolomite occurs, in isolated patches, as far south as Vanceburg, on the Ohio river. The overlying Tymochtee and Put-in-Bay dolomite do not occur south of Fayette county, in Ohio.

8. Dayton limestone

The Dayton limestone, typically exposed in the vicinity of Dayton, Ohio, is a whitish limestone, usually about 4 or 5 feet thick and well bedded. East of the Miami river in Montgomery, Miami, Clark, and Greene counties, fossils are few and confined to isolated specimens of Favosites and straight cephalopods, one specimen of *Pentamerus*, possibly *Pentamerus peeblesensis*, being known from the Dayton limestone southeast of Dayton. However, beginning at Todd Fork, north of Wilmington, Ohio, and continuing thence southward to Sharpsville, in the northwestern part of Highland county, the corals become more numerous, especially in the lower and thinner layers of this limestone, corals occurring at this horizon as far south as Ribolt, in the northern part of Lewis county, Kentucky. In various parts of Highland and Adams counties, especially along the creek one mile west of

Peebles in the latter county, *Pentamerus peeblesensis* is common locally. It is this occurrence of *Pentamerus* which suggests the reference of the Dayton limestone to the upper part of the Lower Clinton. (The Paleontology of Kentucky, p. 185, pl. XIX, figs. 10–13, *1931*.)

While serving as a valuable flagging and building stone in the more northern counties it rapidly deteriorates in the more southern counties in hardness and in the thickness of the individual courses, and never was quarried extensively there.

9. Alger and Ribolt shales

The unfossiliferous Alger clay shale is about 60 feet thick at several localities in the vicinity of Preston, about 4 miles south of Owingsville, in Bath county, Kentucky, where it rests directly on the Oldham limestone. In Lewis county, where it rests on the Dayton limestone, the total thickness of Alger clay shale may be estimated at 70 feet, assuming that the overlying fossiliferous Ribolt clay shale is at least 30 feet thick. At Island Creek, east of Manchester on the Ohio River, the total thickness of the Alger-Ribolt section equals 120 feet. At Marble Furnace this total thickness equals 140 feet. At West Union and at Peebles it is estimated at 150 feet, thinning thence rapidly to 62 feet at Hillsboro. Since the thickness of the Ribolt shale is 30 feet thick one mile west of Peebles and also near the Olive Branch church on the road from Marshall to Sinking Spring, the thickness of the unfossiliferous Alger clay shale can be estimated at about 90 feet at Island Creek, 120 feet at West Union and Peebles, and approximately 40 feet at Hillsboro, exact measurements not having been made at most of these localities.

The Ribolt shale consists of clay shale, similar to that forming the Alger horizon, but interbedded with thin indurated layers of shale not infrequently showing distinct impressions of fossils. Among these are *Liocalymene* cf. *clintoni* and ostracods belonging to the *Mastigobolbina typus* zone of the middle part of the Upper Clinton of more eastern states. The most southern locality at which these fossils occur is at Ribolt, 10 miles west of Vanceburg, in Lewis county, Kentucky. They occur also half a mile west

of Peebles, in Adams county, a mile and a half north of Elmville in the southeastern part of Highland county, and on the hillside near the Bisher bridge, southeast of Hillsboro. (The Paleontology of Kentucky, p. 188, pl. 21, figs. 1–9, *1931*.)

Neither the Alger nor the Ribolt have been identified definitely within the area north of Hillsboro. Although clay shales occur in about the same stratigraphic location farther north, these differ lithologically and contain no trace of the *Mastigobolbina typus* fauna.

No distinct line of separation has been observed between the Alger and Ribolt, therefore, since the Ribolt is known to be of Upper Clinton age, the Alger is referred to the same major division of the Clinton.

10. Bisher formation

At Lilley Hill, on the eastern margin of Hillsboro, Ohio, the thickness of the Bisher formation is estimated at 51 feet. The lower and middle part of the formation consists of yellowish well bedded and more or less arenaceous limestones. Along the lower part of the formation these limestones tend to be more solid and to form thicker layers. Along the middle of the formation they weather more readily into thinner layers, or disintegrate into a sandy clay. At the top, for a thickness of 7 feet, they tend to become laminated or thin bedded, and to become more or less cherty. It is this more thin bedded or shaly horizon which was included by Orton in his Blue Cliff as its basal member. Immediately above the Bisher formation is found the massive blue limestone forming the lower and greater part of the Lilley formation.

Eight feet above the base of the Bisher formation there is a more calcareous zone, 2 feet thick, in which fossils are conspicuously more abundant. At this horizon occur the diagnostic species *Brachyprion plana*, *Schuchertella prosseri*, *Spirifer radiatus*, *Atrypa elongata*, *Camarotoechia roadsi*, *Whitfieldella cylindrica*, *Dalmanites brevicaudatus*, and a species resembling *Bumastus ioxus*. This is the most persistent fossiliferous horizon in

the Bisher formation, being present at numerous localities in Highland and Adams counties in Ohio, and in Lewis county, Kentucky. In Ohio rich faunas have been found at Danville, two miles north of Locust Grove, Sinking Springs, Peebles, and West Union. In northern Kentucky they occur at Harin Hill, Glen Springs, and Martins. Farther southward, the last exposure is seen at the northern margin of Fleming county, Kentucky. Northward it is doubtfully identified at Port William, north of Wilmington, but the formation has changed its character lithologically already before reaching the northern boundary of Highland County. (The Paleontology of Kentucky, p. 189, pl. 19, fig. 9; pl. 21, figs. 11–34, *1931*.)

At Crooked Creek, 4.5 miles north of Sinking Spring, in the northern part of Adams County, Ohio, the following ostracods identified by Ulrich and Bassler occur: *Dizygopleura asymmetrica, Dizygopleura lacunosa, Dizygopleura loculosa, Dizygopleura symmetrica, Paraechmina spinosa,* and *Primitiella equilateralis.* These species are characteristic of the *Drepanellina clarki* zone near the upper part of the Upper Clinton of more eastern states.

Although the horizon from 8 to 10 feet above the base of the Bisher formation is the most fossiliferous and most wide spread identifiable horizon in this formation fossils occur also at other and more irregular levels. In the Lilley Hill section an unidentified species of *Whitfieldella* occurs 32 feet above the base of this formation. The 10 feet of overlying material consists of rather shaly arenaceous limestone, and the overlying 7 feet consist of the cherty horizon, often weathered into thin shaly layers, both of which were included by Orton in the base of his Blue Cliff. These cherty layers in turn are overlaid by the massive bluish argillaceous limestone forming most of the Lilley formation at this locality, the upper part of the latter consisting of the richly fossiliferous clay shale layer, only about 2 feet thick.

11. *Lilley formation*

The Pentamerus horizon at the base of the Peebles formation in the Lilley Hill section at Hillsboro, Ohio, is exposed best in the Zink

or Corporation quarry south of the Marshall pike. Here the top of the immediately underlying Lilley formation is formed by a richly fossiliferous clay shale layer 2 feet thick. This shale includes *Holophragma calceoloides, Zaphrentis digoniata, Cyathophyllum roadsi, Acervularia paveyi, Strombodes striatus, Plasmopora follis, Coenites verticillatus, Halysites labyrinthicus, Brachyprion newsomensis, Atrypa hillsboroensis, Poleumita paveyi, Poleumita prosseri, Diaphorostoma hillsboroensis* and *Dalmanites brevigladiolus.* This is a distinctive fauna, readily distinguishable from that of the overlying Peebles dolomite and from that of the *Bisher* fauna which is most abundant 55 to 65 feet farther down. (The Paleontology of Kentucky, p. 190, pl. 22, figs. 1–10, *1931.*)

In the vicinity of Hillsboro, both east and west, this fossiliferous clay shale is underlaid by a massive, bluish, and more or less argillaceous limestone, varying from 14 to 21 feet in thickness. Since the diagnostic fossils *Holophragma calceoloides* and *Zaphrentis digoniata* occur occasionally at different levels in the upper half of this massive limestone, the latter has been included, along with the overlying clay shale, in the Lilley formation, forming in fact almost all of this formation even at its type locality.

Zaphrentis digoniata was found also about two miles south of Marshall, eastward along the first conspicuous road crossing the road from Marshall to Harriet.

Numerous corals occur also 2 miles north of Locust Grove, immediately north of Crooked Creek, four and a half miles south of Sinking Spring, in the northern part of Adams county, Ohio. However, none of the species occurring here are definitely diagnostic of the Lilley formation as exposed on Lilley Hill.

At present the Lilley formation is well known only in the immediate vicinity of Hillsboro, Ohio. No continuous effort has been made to trace it elsewhere. The presence of the Gotlandian species *Holophragma calceoloides* suggests an eastern derivation, but no corresponding fauna is known in more eastern parts of the United States. There is a slight resemblance of the coral fauna to that in the Louisville limestone, but not sufficient to warrant their correlation.

12. Peebles formation

The Peebles formation includes that part of the Niagaran which lies above the Lilley formation in the limited area where the latter is present, but immediately above the Bisher formation at all other localities. It is overlaid by the Greenfield member of the Monroe group wherever the latter is present. Elsewhere it often is overlaid directly by the Devonian Black Shale, and locally it is overlaid occasionally by the Hillsboro sandstone.

The typical section is that between Peebles, Ohio, where it rests on the Bisher formation, and the base of the Greenfield dolomite several miles eastward.

At Hillsboro, Ohio, only the basal part of the formation is preserved. The total thickness of the formation exposed here equals about 60 feet. *Pentamerus oblongus* occurs at the base of this section and also in the 10 feet at its top. A short distance beneath the upper *Pentamerus* horizon *Megalomus canadensis* formerly was present in abundance in the Trimble or railroad quarry along the northern extension of Lilley Hill. At the Caves on Rocky Fork in the eastern part of Highland County there is a measured section 90 feet thick in which *Megalomus* occurs from bottom to top. It is evident that the total thickness of the Peebles formation in Highland and Adams counties must be considerably greater than 100 feet. *Trimerella* is another important element of the Peebles fauna locally. According to Orton it is common on Cedar Fork of Scioto Brush Creek in Adams County, the three species *Trimerella grandis, Trimerella acuminata,* and *Trimerella ohioensis* having been found there. In southern Ontario *Megalomus* and *Trimeralla* are characteristic of the Guelph. Other species found in the Guelph, such as *Pycnostylus guelphensis,* and *Goniophora crassa,* also occur in the Peebles formation. The unusual element is to find *Pentamerus* so abundant in the lower half of this Peebles horizon. Apparently it occurs not only beneath, but also above the lowest horizons holding *Megalomus,* both being long ranging species in southern Ohio.

The Peebles dolomite has been identified definitely as far south as the Ohio River, where it crosses evidently into Lewis County,

but here it soon disappears under cover of the Devonian Black shale. In a northward direction it has not been identified definitely north of a line connecting Hillsboro and Bainbridge, though undoubtedly connecting northward with the Guelph formations occurring in the northwestern parts of Ohio, where *Megalomus* and *Trimerella* occur near the top of the Niagaran.

Orton was well aware of the great difference between the faunal characteristics of the Peebles dolomite contrasted with that of the Cedarville dolomite. In the Cedarville dolomite the dominating types are crinoids, cystids, cephalopods, and trilobites having their nearest affinities with the Racine of southeastern Wisconsin and northeastern Illinois, while the fauna characteristic of the Peebles dolomite has its nearest affinities with that of the Guelph of northwestern Ohio and southern Ontario.

In west-central Ohio, where not exposed or at least not identified, the Peebles dolomite or its equivalent probably rests on the Cedarville dolomite. The latter is typically exposed within the southeastern margin of Wilmington, in Clinton county, Ohio.

In the upper part of the Trimble quarry on the northern extension of Lilley Hill, at Hillsboro, the upper parts of the Peebles section there exposed are coarsely porous and more or less distinctly bituminous. Similar lithological conditions exist at exposures northwest of Hillsboro, also on roads leading from Hillsboro northward to New Vienna and Leesburg, and in the vicinity of Snow Hill, on the road from New Vienna to Wilmington, but it has been impossible so far to determine whether these exposures contain faunas indicative of Peebles age, or whether they belong neither to the Peebles nor to the Cedarville.

E. SILURIAN OF WESTERN OHIO

In the preceding lines attention has been called to the difficulty of tracing the various Niagaran formations, as exposed in Lewis, Adams, and Highland counties northward of Hillsboro, Ohio. A similar difficulty obtains in attempting to trace the Niagaran formations of Clark, Greene, and Clinton counties southward beyond Wilmington. The area between Hillsboro and Wilmington is debatable ground. This may be remedied in course of

time by a better knowledge of the faunas of the intermediate area, but at present the exposures appear inadequate.

In Clark and Greene counties the Silurian strata present the following sequence, in descending order:

Cedarville dolomite
Springfield dolomite
Euphemia dolomite
Massie clay
"Laurel" limestone
"Osgood" clay
Dayton limestone
Brassfield limestone
Centerville clay shale

13. Brassfield limestone

In east-central Kentucky, as far north as Hillsboro, in Fleming county, the Brassfield formation usually does not exceed 20 feet in thickness. Farther north its thickness increases gradually to 40 feet in the area between West Union and Peebles, Ohio, probably attaining thicknesses of even 50 feet locally in more northern parts of Adams and Highland counties. Thicknesses of 40 feet may exist also in the eastern half of Greene county and the central parts of Clark county, but no actual measurements are on record from these more northern exposures.

However, westward from Clark county, Ohio, the thickness of the Brassfield formation thins conspicuously from 28 feet at Ludlow Falls to 22 feet at Lewisburg, and to 14 feet at Elkhorn Falls, 4 miles south of Richmond, Indiana, a reduction to half of its thickness at Ludlow Falls in a distance of 30 miles. Similar thinning is shown from Dayton and Centerville westward.

A similar thinning probably took place also westward from Hillsboro and West Union, Ohio, since the Brassfield is entirely absent 100 miles farther west, in the areas west of Versailles and Osgood in the western part of Ripley county, Indiana, and in the adjoining parts of Jennings and Decator counties. Unfortunately, no definite records are available in the intermediate areas.

South of Ripley county the thickness of the Brassfield rarely exceeds 3 feet as far south as the areas east of Louisville, Ken-

tucky, increasing in thickness farther south toward Bardstown and Raywick.

It is possible that in early Silurian times the dominant axis of elevation of the dome then in existence in adjacent parts of Ohio, Indiana, and Kentucky lay farther west than the crest of the present Cincinnati dome or anticline; possibly reaching its maximum in eastern Indiana.

Farther south, in northern Tennessee, and probably also in the adjacent parts of Kentucky, the Brassfield thickens conspicuously westward from its most eastern exposures in Sumner county, indicating that the crest of the Nashville dome lay farther east, in agreement with the usual interpretation of this dome.

In the area east of the Cincinnati anticline in Kentucky and southwestern Ohio, notwithstanding differences in thickness and some differences in lithological appearance, certain features are remarkably constant. Throughout this area the basal part of the Brassfield usually is more massive, poorly bedded, and poorly fossiliferous. Farther up, the bedding is more distinct and the fossils become more numerous, but it is only in the upper fourth of the formation, where the limestones often are more or less interbedded with clay, that the fossils are abundant and occur in great variety. At the top of the Brassfield large crinoid columnals often 11 or 12 mm. in diameter, but occasionally reaching 20 mm., and rarely even 28 mm., are widely distributed throughout the area in question. At this crinoid columnal horizon, or immediately above, wave-marks with crests about 2 feet apart and about one inch in height are common, and locally this overlying rock becomes strongly ferruginous at the top. The Soldiers Home west of Dayton and the large quarry half a mile northeast of Centerville have been especially prolific in numerous species of fossils, partly due to frequent collecting. (The Paleontology of Kentucky, p. 175, pls. 17, 18, 19, *1931*.)

In Highland county, intraformational pebbles occur throughout the length of the county from north to south, from Sharpsville to Belfast, ranging from the middle of the Brassfield into the overlying layers. At the Elk Run bridge, 2 miles east of Belfast, large pebbles are common in the ferruginous and wave-

marked layer at the top of the Brassfield, many of these pebbles being 4 to 8 inches long, and some of them equalling even 12 inches. Possibly there is some significance in the fact that these pebbles in the Brassfield of Highland county, Ohio, occur directly east from Ripley county, Indiana, where pebbles occur in the basal 4 to 6 inches of the formation. Here the pebbles usually do not exceed one inch in length, though occasionally equalling 2, and even 3 inches.

14. Platymerella manniensis zone

At the quarry northeast of Lawshe, 4 miles west of Peebles, Ohio, *Platymerella manniensis* occurs in a thin layer of limestone at the base of the Brassfield formation. The chief interest in this occurrence is the presence of the same species in the same relative position in Pike county, Missouri, and in Pike, Calhoun, and Jersey counties of southern Illinois; also in the southwestern corner of Will county, 15 miles northwest of Kankakee, in the northeastern part of the same state. Originally this species was described from Riverside, Lewis county, and Iron City, Lawrence county, in southcentral Tennessee. Evidently there was some area where this more western species was able to enter the region east of the Cincinnati anticline. (Denison Univ. Bull., Jour. Sci. Labs., vol. 19, p. 223, pl. 23, figs. 5 A–H, *1920*.)

15. Belfast zone

In this same area east of the Cincinnati anticline the base of the typical Brassfield limestone is underlaid by an argillaceous, bluish, and usually massive limestone, from 3 to 6 feet thick, which contains annelid teeth at Todd Fork north of Wilmington, Ohio, at Sharpsville in the northwestern margin of Highland county, and at Belfast in the southeastern corner of the same county. The presence of *Halysites* in this argillaceous limestone suggests that it is of Silurian age, though a distinguishable species is known also from Richmond beds in other areas. At the Whippoorwill chapel, 2.5 miles northeast of West Union, it contains *Platystrophia daytonensis*, described originally from the Brassfield. The name *Belfast* bed or formation was supplied to this

argillaceous limestone zone by Foerste in 1896. Strata of a similar lithological appearance underlie the typical Brassfield limestone as far south as Duncansville and West Union, in Adams county, Ohio, and Hillsboro, in Fleming county, Kentucky. (American Geologist, vol. 2, pp. 412–419, *1888*.)

Northward from Todd Fork near Wilmington, Ohio, indurated argillaceous rocks occur immediately beneath the typical Brassfield limestone as far as the High Banks between Tippecanoe City and Troy, but the lithological appearance of these indurated argillaceous rocks differs sufficiently from that of the typical Belfast bed to make their identity uncertain.

16. Centerville formation

At the large quarry half a mile northeast of Centerville, Ohio the typical Brassfield limestone is underlaid by indurated clay, about two and a half feet thick. The digging of a drainage ditch through this indurated clay exposed numerous fossils, including about 13 species, of which the brachiopod genera *Schuchertella*, *Brachyprion*, and *Whitfieldella*, and a Silurian form of *Dalmanites* indicate Silurian affinities. The typical Belfast bed is not exposed here.

About 2 miles south of Lawshe, on the eastern side of Brush creek, the Belfast bed is 5.5 feet thick. In the underlying argillaceous rock Prof. W. H. Shideler found a species identified as *Rhynchotreta thebesensis*. Along Beasley Fork, south of West Union, where the typical Belfast is 1 foot thick, he found both *Rhynchotreta thebesensis* and an unidentified species of *Whitfieldella* at a horizon 4 feet beneath the Belfast. (The Paleontology of Kentucky, p. 184, pl. 19, figs. 15–20, *1931*.)

For this Silurian horizon below the typical Belfast the name *Centerville* formation was proposed by Foerste in 1931. No attempt has been made so far to trace the area within which this Centerville fauna may be detected.

In a general way it corresponds to the Edgewood formation of Savage, as exposed typically in southwestern Illinois and the adjacent part of Missouri, and also in Will county, in the northeastern part of Illinois. The occurrence of both the Centerville

formation and of the *Platymerella* zone at the base of the Brassfield in the vicinity of Lawshe, favors such a tentative correlation, though no species identical with any occurring in the typical Edgewood is known so far from any exposure of the Centerville formation in Ohio.

17. Beavertown marl

The term *Beavertown* marl was applied by Foerste in 1885 to an indurated fine-grained argillaceous rock which rests directly on top of the typical Brassfield formation at various localities in the vicinity of Dayton, the more fossiliferous phases being located near Beavertown, southeast of the city, and southeast of the Soldiers Home, west of the latter. On long exposure this argillaceous rock weathers into a whitish clay, but the fauna of this Beavertown marl is readily distinguishable from that which characterizes the immediately underlying soft clay of the Brassfield formation in the Dayton area.

The more characteristic species of this Beavertown marl are depauperate, including forms identified as *Plectatrypa* cf. *marginalis, Ctenodonta ohioensis, Ctenodonta? minima, Bellerophon exiguus, Bellerophon opertus, Bucaniella trilobata, Cyclora alta, Liospira affinis,* and *Orthoceras inceptum.* The holotype of *Aspidopora parmula* was found in this marl. However, the occurrence of this species of bryozoan also in the underlying typical Brassfield suggests that the Beavertown marl is essentially of the same age as the Brassfield, differing chiefly in its depauperate fauna. (Geol. Surv. Ohio, vol. 7, pl. 25, figs. 1, 6, 18, 18a; pl. 26, figs. 8, 17, 18; pl. 27, fig. 33; pl. 37, figs. 12, 13, *1893.*)

18. Dayton limestone

The name Dayton limestone was in use commercially long before it was introduced as a stratigraphic term by Orton in 1871. It designates a white and relatively fine-grained, well-bedded limestone, in fairly thick courses, resting directly on the Brassfield limestone. In the Dayton area this limestone varies usually between 4 and 5 feet in thickness, and formerly it was quarried extensively in Montgomery, Miami, and Preble counties. At

Covington, in Miami county, it is 8.3 feet thick, and at Ludlow Falls, farther south, Prosser measured a thickness of 11.5 feet. At Lewisburg and New Paris, in Preble county, its thickness is 7 or 8 feet, and in the vinicity of Longwood and Laurel, in Indiana, the equivalent of the Dayton limestone does not exceed this thickness. South of the Dayton area the Dayton limestone can be traced through Clinton, Highland, and Adams counties, Ohio, into the adjacent parts of Lewis county, in Kentucky.

In Adams and Highland counties the transition from the Dayton limestone to the overlying Alger clay usually is abrupt. Farther north, however, and as far west as Centerville and Dayton, the thicker and more solid layers of limestone, which form the lower and more characteristic part of this Dayton limestone, are overlaid by thinner, more argillaceous, and more readily weathering layers of limestone which become interbedded with thin layers of clay, the latter increasing in thickness toward the top, and finally the limestone series is overlaid by clay shales in which layers of limestone either are few or absent. That part of the section in which the limestone greatly preponderates over the clay shale here is included in the Dayton limestone, while the overlying clay shale here is called the *Osgood of Ohio*, since it appears to be a continuation eastward of the clay shale occurring at the top of the Osgood formation at Laurel, Indiana, although there is no paleontological evidence in favor of such a correlation.

At the Jackson quarry, south of Covington, in Miami county, Prosser measured a section of Dayton limestone 8.3 feet thick, the corresponding section at Ludlow Falls, about 6 miles farther south, equalling 11.5 feet.

In the immediate vicinity of Dayton and Centerville, and thence northward and eastward, the fauna of the Dayton limestone consists of a few specimens of *Favosites favosus*, *Favosites niagarensis*, and of a still smaller number of *Dawsonoceras* and undetermined smooth orthoceroids. West of Dayton, at the Soldiers Home, Trotwood, and Lewisburg, the thinner bedded layers of the Dayton limestone contain the following fauna: *Enterolasma caliculum*, *Favosites favosus*, *Favosites niagarensis*, *Clathrodictyon vesiculosum*, *Chasmatopora angulata*, *Rhinopora ver-*

rucosa, *Clidochirus ulrichi*, *Atrypa reticularis*, *Coelospira* sp., *Leptaena rhomboidalis*, *Orthis flabellites*, *Platystrophia daytonensis*, *Platystrophia reversata*, *Rhipidomella hybrida*, *Schuchertella subplana*, *Eospirifer niagarensis*, *Eospirifer plicatellus*, and *Whitfieldella* sp. This is chiefly a brachiopod fauna, which probably invaded from the same source as the Brassfield. The fauna is not diagnostic and does not demand correlation with the Osgood of Indiana.

19. Osgood clay

The fauna found in the so-called Osgood clay immediately overlying the Dayton limestone at Rocky Point, 3 miles northeast of Eaton, Ohio, consisting of *Enterolasma caliculum*, *Atrypa reticularis*. *Leptaena rhomboidalis*, *Orthis flabellites*, *Schuchertella subplana*, and *Eospirifer* cf. *niagarensis*, presents nothing distinctive, and explains why the tracing of the Dayton limestone of Ohio and of the overlying clay shale into neighboring Indiana has not reached a more definite stage.

South of Yellow Springs, Ohio, on the Bryan Farm State Park, the clay shale there identified as approximately equivalent to the Osgood clay of the more western parts of Ohio, in Preble county, is approximately 35 or 40 feet thick. At the Shoup quarry on the road from Dayton to Troy, on the east side of the Miami River, 7 miles north of Dayton, the thickness of this Osgood clay section, down to the top of the Dayton limestone as exposed westward, is estimated at 25 feet. At Lewisburg, and at New Paris, where this clay becomes strongly indurated and is known locally as soapstone, its thickness is reduced to 4 feet. Farther southwest, in the vicinity of Longwood and Laurel in Fayette and Franklin counties, Indiana, the indurated clay there identified with the soapstone of Preble county, Ohio, does not exceed 20 inches in thickness and frequently is reduced to 12 inches.

These observations suggest a westward thinning of the Osgood clay section from Clark and Greene counties in Ohio as far west as Fayette and Franklin counties in Indiana. At New Point, in the southeastern corner of Decatur county, this soapstone is still 20 inches thick, the underlying Osgood limestone equalling 8 feet,

neither showing any conspicuous change in thickness since leaving Fayette county.

However, a similar thinning apparently takes place also northward from Montgomery county, Ohio, since Prosser recorded a thickness of 3.2 feet for the Osgood indurated clay at Ludlow Falls, and of 1.7 feet at the Jackson quarry about 2 miles south of Covington.

The great total thickness of the Alger and Ribolt clay shales in southern Ohio and thence southward as far as east central Kentucky, and their total absence in Indiana, suggests a westward thinning also of these clay shales, within the boundaries of Ohio, although no records are known demonstrating such a thinning.

The identification of the Osgood formation in areas farther north than Ripley county in Indiana is based altogether on the stratigraphical sequence of these strata in relation to other formations here exposed, since the fauna typical of the Osgood in Ripley and more southern counties can not be traced farther north.

20. Laurel limestone

The limestones overlying the indurated clay or soapstone, which in turn overlies the Dayton limestone, in Preble and Miami counties of Ohio, there are identified with the Laurel limestone as described originally from the vicinity of Laurel near the northern margin of western Franklin county, Indiana. This correlation is based solely on stratigraphical grounds, the fossiliferous part of the Laurel being limited chiefly to the upper part of the Laurel section as exposed much farther westward, in the area between the eastern part of Shelby county and the northwestern part of Jefferson county, in Indiana.

At the Bryan Farm State Park south of Yellow Springs, Ohio, the limestone there identified as Laurel is 5.7 feet thick, and is separated from the overlying Euphemia dolomite by the Massie clay shale which is 5.5 feet thick, and which on Massie creek, west of Cedarville, carries a typical Waldron fauna. At Ludlow Falls, this Laurel limestone is 7.2 feet thick, and at the Jackson quarry, south of Covington, it is 9 feet thick.

At Lewisburg, where the Laurel limestone is overlaid directly

by the Euphemia dolomite, its thickness is nearly 9 feet. At New Paris, under similar conditions, the thickness of the Laurel limestone is 25 feet, the lower two thirds being very cherty.

In the vicinity of Laurel, Indiana, only the lower part of the Laurel limestone is exposed, this part nowhere exceeding 12 feet in thickness. Farther westward, in Decatur county, several sections of the Laurel limestone are known which equal at least 30 feet, the thickest section known at present being that at St. Paul, in the southeastern part of Shelby county, where it equals 37 feet.

The preceding observations suggest that the Laurel limestone thins out eastward from the St. Paul area in Indiana at least as far as Yellow Springs, in Ohio. It may be present at Cedarville, Ohio, but here the strata beneath the Massie or Waldron clay are not exposed. Apparently the axis of the Cincinnati dome during Laurel times was considerably farther east than during Brassfield, Alger, and Ribolt times, or during the deposition of the so-called *Osgood of Ohio.*

21. Massie clay

The only exposure in Ohio of a fauna closely resembling that of the Waldron clay shale of Indiana, as far as known at present, is on Massie creek, a short distance west of Cedarville, in Greene county. Here the fauna occurs in a clay shale, for which the term *Massie* clay shale is proposed, on the north side of the creek, at a well known spring, directly beneath the Euphemia dolomite. Only about 6 feet of the shale are exposed here, containing *Streptelasma radicans, Eucalyptocrinus crassus, Schuchertella subplana, Leptaena rhomboidalis, Sowerbyella transversalis, Dalmanella elegantula, Eospirifer radiatus, Atrypa newsomensis, Dictyonella reticulata, Strophostylus* cf. *cyclostomus*, and *Dalmanites verrucosus.* Lithologically this clay shale closely resembles that of the typical Waldron of Indiana.

At the Bryan Farm State Park, south of Yellow Springs, about 5 miles northwest of Cedarville, the clay layer immediately underlying the Euphemia dolomite also is identified as Massie or Waldron clay shale, though no diagnostic fossils were found here. At this locality the Massie clay is 5.5 feet thick and is underlaid

by a limestone section, 5.7 feet thick, identified as Laurel limestone.

These are the only two exposures in Ohio where strata identified as Waldron are known. Apparently the Waldron, Laurel, and Osgood of Indiana had direct connection with more eastern areas, in the western part of Ohio, across Preble, Montgomery, Greene and more northern counties. It should be noted that Cumings has found a sequence resembling that of the Euphemia, Springfield, and Cedarville of approximately the same part of Ohio as far west as Ridgeville, Indiana, about 25 miles northwest of Greenville, Ohio. Moreover, the affiliation of the Cedarville dolomite is closer to the Racine of southern Wisconsin and adjacent Illinois than to any other Silurian area known at present, though the line of connection is unknown.

22. *Euphemia dolomite*

At Springfield, Ohio, the Euphemia dolomite is 8 feet thick. It lies immediately beneath the typical Springfield dolomite and is underlaid by the Massie clay. Although this Massie clay no longer is well exposed in Clark county, it is clearly exposed just south of this county, at Yellow Springs, and farther south also at Cedarville. It is probable that both the Massie clay and the so-called Laurel limestone of Greene county extend northward into Clark county, though covered now by glacial deposits.

The Euphemia dolomite is massive, porous, and more or less mottled. This mottled appearance is due to denser and lighter colored patches of rock irregularly distributed throughout its more porous parts, the latter usually being somewhat darker.

At Cedarville, this Euphemia dolomite is 7.5 feet thick. At the Jackson quarry, south of Covington, it is 7.2 feet; at Ludlow Falls it is 5.5 feet, at Lewisburg, it is 4.5 feet, and at New Paris, it is 2.6 feet in thickness. Apparently it should disappear soon after crossing westward into Indiana, but possibly it might be identified as far west as Ridgeville in that state.

It has not been identified anywhere south of Cedarville.

Its fauna contains occasional specimens of *Pentamerus*, and other fossils suggestive more of the overlying Springfield and

Cedarville than of any known underlying strata in southwestern Ohio.

23. *Springfield dolomite*

The term Springfield as a stratigraphic name was introduced by Orton in 1871. The type locality was Springfield, Ohio, where this formation long has been quarried west of the city. Here the typical well-bedded Springfield rock is 10 feet thick, the underlying dense, but somewhat mottled rock being 4 feet thick, giving a total of 14 feet for the entire Springfield dolomite section. At Cedarville, the rock weathering into thin and fairly well bedded layers is 13 feet thick, and this is its thickness also at Covington, and at the Jackson quarry two miles south. At Lewisburg its thickness is 7.7 feet and at New Paris it is 6 feet. Judging from these observations it is not improbable that the Springfield dolomite thins out westward. However, it might be present at Ridgeville, in accordance with observations kindly supplied to the present writer by Cumings.

At the exposure along the creek half a mile west of Port William, near the northern edge of Clinton county, there is no trace of a distinctly bedded Springfield dolomite, though the Cedarville dolomite and an underlying indurated clay formation is well exposed downstream, on the south side of the road leading to Lumberton. The Cedarville is exposed also at Wilmington; however, the Springfield has not been identified definitely anywhere south of Cedarville.

In its typical area the Springfield consists of a well bedded, fine-grained dolomite, in which *Pentamerus* cf. *oblongus* is abundant at several horizons. At Springfield, *Pentamerus* and *Calymene celebra* are the fossils most readily detected, but at the Jackson quarry, about 2 miles south of Covington, Ohio, more than 25 species have been collected from this dolomite. The Springfield form of *Pentamerus* is identical with that illustrated by Hall and Clarke, in Paleontology of New York, vol. 8, pt. 2, pl. 68, fig. 4, from Yellow Springs, Ohio.

The more porous dolomite overlying the typical Springfield dolomite at Covington, Lewisburg, and New Paris, Ohio, has been

referred to the Cedarville both by Prosser and Foerste, but the typical Cedarville fauna never has been found within the socalled Cedarville dolomite at these localities, while *Pentamerus* is abundant at its base at the Jackson quarry. At the Lewisburg quarry it is abundant 7 feet above the base of the Cedarville, but occasional specimens occur in the 3 feet immediately underlying this Pentamerus horizon. At New Paris occasional specimens occur in the lower two-thirds of the 27 foot section there included in the Cedarville. The absence at these localities of the characteristic Cedarville fauna so well exposed in the vicinity of Greenville, Ohio, suggests that the identification of these more southern exposures as Cedarville may be in error.

24. Cedarville dolomite

The term Cedarville as a stratigraphic unit was introduced by Orton in 1871. The type locality was Cedarville Ohio. Here Foerste estimated a thickness of 55 feet for that part of the Cedarville which extends from the top of the quarry west of the railroad station to the base of the Cedarville on Massie Creek half a mile farther west. This is the thickest section actually measured from exposures anywhere in Ohio, but it evidently represents only the lower part of the total Cedarville section since at no locality in southwestern Ohio has it been possible to discover the Cedarville in contact, or even near contact with any overlying Silurian formation. Its total thickness in Ohio may equal at least 100 feet.

At its typical area of exposure the Cedarville dolomite is massive, poorly bedded, and distinctly porous. This is in such strong contrast with the underlying well bedded and relatively dense Springfield dolomite lithologically that it attracts immediate attention. Moreover, the porous Cedarville burns readily to a lime, while the well bedded Springfield long was a source of flagstone and building stone. Moreover, at most localities the fauna of the Springfield consists chiefly of *Pentamerus* cf. *oblongus*, and *Calymene celebra*, while a much more abundant fauna is known from the Cedarville. The affinities of this Cedarville fauna are close to that of the Racine of southeastern Wisconsin and northeastern Illinois, many species being held in common.

This Cedarville fauna occurs as far south as Wilmington, in Clinton county, where a rich cephalopod fauna was found in the old Moodie quarry within the southeastern limits of the city. Farther south, in the vicinity of Snow Hill and other localities north of New Vienna, it has not been possible to identify the rock as Cedarville, though dolomitic rock of either Cedarville or Guelph age occurs there.

Typical Cedarville faunas occur as far west as the old Bierley quarry several miles east of Greenville, on Greenville creek, and at the Gard quarry a mile and a half southeast of the city. At the Bierley quarry crinoids and cystids dominate. At the Gard quarry brachiopods, gasteropods, and cephalopods dominate. Fossils of both types have been found at the Cedarville and Springfield exposures of the Cedarville dolomite.

In this connection it should be noted that Lindemuth, in his report on the geology of Darke county in 1878, stated that *Pentamerus oblongus* in this area was rare, but 4 or 5 specimens having ever been found, though the Greenville localities are only about 15 miles north of a line connecting Lewisburg with New Paris. It is possible that the exposures near Greenville belong stratigraphically at a higher horizon than the exposures at the more southern localities just named. Unfortunately the amount of dip of the rocks northward and eastward within the area in question has not been determined, but if this dip is northward the probabilities are at least in favor of the higher stratigraphical position of the exposures near Greenville.

F. SILURIAN OF NORTHERN INDIANA

25. Niagaran at Ridgeville, Indiana

At the quarry half a mile east of Ridgeville, Indiana, and about 25 miles northwest of Greenville, Ohio, Cumings found the following strata, in descending order:

	feet
6. Slabby yellow dolomite, snow-white when fresh; texture saccharoidal; with many Guelph fossils	15
5. Gray, pseudo-oölitic, iron-stained dolomite, with some fossils	5
4. Grayish-blue dolomite mottled yellow and pink	8

	feet
3. Massive, bluish-gray dolomite with *Pentamerus oblongus* abundant.	10
2. Massive blue to gray dolomite with *Pentamerus oblongus* common.	10
1. White to gray, mottled, saccharoidal dolomite	22

In this sequence, the massive dolomites containing many specimens of *Pentamerus oblongus* suggest the Springfield horizon of western Ohio, while the slabby yellow dolomite with many Guelph fossils suggests the Cedarville dolomite, at least stratigraphically.

There is no doubt of the Huntington affinities of slabby yellow dolomite. That is indicated by the occurrence of such typical species as *Conchidium laqueatum* and *Bickmorites bickmoreanum.* It is assumed that the species identified as *Pentamerus oblongus cylindricus, Turritoma laphami,* and *Phragmoceras parvum* are identical with the species figures under these names by Kindle and Breger from the Huntington formation of Delphi and Indiana, and not with the forms upon which these species were founded.

The only species suggesting affinities with the Cedarville is *Subulites terebriformis,* which was described originally from the Cedarville dolomite at Clifton, 3 miles southeast of Yellow Springs, Ohio.

In other words, the affinity of the strata at the top of the Silurian section at Ridgeville, Indiana, appears to be with the Huntington dolomite of northern Indiana rather than with the Cedarville dolomite of Ohio.

There is a distinct lithological change between the typical Springfield and Cedarville dolomites of western Ohio and their supposed equivalents in the Ridgeville area of Indiana, The typical Springfield is well bedded, forming an excellent flag and building stone. The *Pentamerus* horizon at Ridgeville is described as massive, and no mention is made of bedding. The typical Cedarville, on the other hand, is massive, porous, and poorly bedded, while that part of the section at Ridgeville which contains many Guelph fossils is described as slabby, snow-white when fresh, and saccharoidal in texture.

It is these lithological differences between the Ohio and Indiana exposures, without adequate intermediate outcrops, which make attempts at correlation so difficult, though the distance intervening is only 25 miles.

26. Niagaran of northern Indiana

A similar difficulty arises when it is attempted to correlate the Niagaran strata of northern Indiana with those exposed in the southern half of this state.

The Louisville limestone appears to be absent in areas east of Greensburg, Indiana, and it can not be identified north of Rush county. The Waldron clay is typically exposed at Waldron, in the southeastern part of Shelby county, and is 1.5 foot thick at Milroy in the southern part of Rush county, but farther north it appears to be replaced by limestone. The Laurel limestone is well exposed at St. Paul, east of Waldron, and its top may be identified at Milroy. Farther eastward, only the lower part of the Laurel is exposed; at Laurel for a thickness of 12 feet, and at Longwood for a thickness of only 4.5 feet. The Osgood is exposed typically in Ripley county. Fossils are numerous in its upper part as far north as New Point, in the southeastern part of Decatur county. Westward it can be traced as far north as St. Paul, and eastward as far north as Longwood, in Fayette county,

In the northern half of Indiana the Niagaran strata are divided by Cumings into the following formations, in descending order:

New Corydon
Huntington
Liston Creek
Mississinewa

The New Corydon formation is not exposed anywhere south of the northeastern corner of Jay county. The Huntington formation has not been identified south of the northern half of Randolph county. The Liston Creek formation is not known south of Ingalls, near the southern margin of Madison county. The Mississinewa shale is exposed only in the valleys cut by streams passing through territory in which the Liston Creek is the dominating formation. The most southern exposures of the Mississinewa shale are on the White River where passing through Delaware and Madison counties.

This leaves an area between 35 and 40 miles wide between the most northern exposures of the Niagaran of southern Indiana and

that of northern Indiana within which no outcrops are known which might be of assistance in correlating strata exposed in these two distinct areas. The difficulties are lithological as well as paleontological. The studies made by Cumings and Shrock in northern Indiana are in great detail, both stratigraphically and paleontologically, and represent the best work done so far within this area but they leave much to be determined, chiefly owing to inadequate exposures.

It has already been stated that they correlated the Huntington dolomite with the Cedarville-Springfield-Euphemia sequence of western Ohio. The Liston Creek formation contains a clay shale bed containing fossils suggesting Waldron affinities. Regarding this bed Cumings supplied the following information in a letter to the writer:

The shale bed mentioned (in The Geology of the Silurian Rocks of Northern Indiana, by Cumings and Shrock) at Huntington, Ingalls, Marion, and along Mississinewa river, in the Liston Creek formation, is in all cases the same bed, at about the middle of the Liston Creek. At Huntington it is not fossiliferous. At Ingalls there are a few bryozoa and brachiopods. At Marion it is quite fossiliferous and practically all of the bryozoa and brachiopods listed from there are from this bed. It is somewhat more calcareous and better indurated than the Waldron shale of southern Indiana. The Liston Creek below it at Ingalls is strikingly like the cherty Laurel of Greensburg and vicinity; but there are practically no fossils.

Foerste found a similar clay shale containing a fauna with Waldron affinities in the eastern part of Muncie, Indiana, in a quarry at the Wire Works west of the river. Here the clay shale is a foot and a half thick, its upper part interbedded with very thin layers of limestone, containing *Duncanella borealis*, *Favosites forbesi-occidentalis*, *Favosites spinigerus*, *Hallopora elegantula*, *Diamesopora osculum*, *Trematopora singularis*, *Eucalyptocrinus* sp., *Atrypa reticularis*, *Anastrophia internascens*, *Camarotoechia acinus*, *Leptaena rhomboidalis*, *Rhipidomella hybrida*, *Rhynchotreta cuneata-americana*, *Schuchertella subplana*, *Delthyris crispus-simplex*, *Whitfieldella nitida*, *Cypricardinia arata*, *Diaphorostoma niaga-*

rense, and *Dalmanites verrucosus*. This fauna occurs 45 feet below the level of the railroad following the west side of the river near the quarry. The rock immediately above this horizon, for a thickness of 25 feet, is porous and massive and contains a species of *Conchidium*. Farther up, for a thickness of 12 feet, the rock is thin-bedded and richly fossiliferous, containing *Pentamerus compressus* or a closely related form. The rock below the clay shale contains *Petalocrinus* sp., and a crinoid identified as *Saccocrinus benedicti*. This might admit of Laurel age, but the entire thickness of the rock here exposed beneath the shale is dolomitic and massive, without well marked bedding planes, while the typical Laurel is a well bedded limestone.

In 1928 Shrock published descriptions of 28 species of graptolites from the Mississinewa shale, all but two of which were found at Yorktown, about 6 miles west of Muncie, Indiana. Of these, 8 were identified from Markle, in eastern Huntington county, 5 from Wabash, 3 from Lagro six miles northeast of Wabash, and one species each from Red Bridge eight miles south west of Wabash, and from the vicinity of Kokomo. Of the 28 species described from the Mississinewa shale 15 are known also from the Niagaran at Hamilton, Ontario, where they occur at a horizon distinctly beneath the typical Lockport and above the typical Rochester. This would suggest a position beneath the Laurel of southern Indiana and above the Osgood of that part of the state. It is scarcely necessary to state that such attempts at correlation can only be tentative.

G. INDIANA FORMATIONS IN WESTERN OHIO

27. *Osgood-Laurel-Waldron sequence in western Ohio*

The Osgood-Laurel-Waldron sequence of southern Indiana apparently can be followed into Preble, Miami, Montgomery, Clark, and Greene counties of western Ohio more readily than into the northern half of Indiana.

The typical Osgood formation is exposed at Osgood, in the central part of Ripley county. Farther south, in Jefferson and Clark counties and also in the adjacent parts of Kentucky, the greater part of the Osgood formation consists of a soft, unfossi-

liferous clay shale, overlaid by relatively thin limestones interbedded with thinner layers of clay, both usually fossiliferous, and the latter in turn by two or three feet of clay shale, also containing fossils locally, but in smaller numbers. In Ripley county the upper part of the lower clay section becomes more indurated and passes northward into an argillaceous rubble. At New Point, in the southeastern part of Decatur county, the lower part of the Osgood formation consists of an argillaceous limestone, 4 feet thick, the limestone often occurring in streaks interbedded with indurated clay rock. Above this are 4 feet of fossiliferous limestone of which the middle portion formerly was quarried for bridge stone. The top of the formation consists of an indurated clay shale or soapstone nearly 2 feet thick.

At Laurel, the lower part of the Osgood formation, 3.5 feet thick consists of thin layers of soft argillaceous limestone, corresponding to the much thicker Lower Osgood clay of more southern areas. This is overlaid by 3 feet of thicker limestone layers, corresponding to the Osgood limestone of southern Indiana. The top is formed by an indurated clay or soapstone 2 feet thick, corresponding to the Upper Osgood clay of more southern sections.

It is this Upper Osgood clay or soapstone which is identified farther east, in Ohio, as the Osgood formation, while the underlying part of the Osgood formation as exposed at Laurel, Indiana, is called the Dayton limestone in those counties of Ohio named above.

The apparently sudden great increase in thickness of the Upper Osgood clay in the areas east of the Miami River, in Montgomery and Greene counties, Ohio, can not be explained, chiefly owing to lack of adequate intermediate exposures.

The identification of the clay immediately beneath the Euphemia dolomite, in Greene county, as Waldron is based chiefly on its fossil content at Cedarville, in that county. The Laurel formation in that area includes merely that limestone zone which intervenes between the base of the Waldron clay shale and the supposed Osgood clay shale, there being no diagnostic fossils known from the limestone there identified as Laurel. If this identification is correct then the Laurel formation of southern

Indiana thins rapidly eastward in the more central parts of that state.

H. SILURIAN OF SOUTHERN INDIANA AND WESTERN KENTUCKY

The Silurian sequence characteristic of southern Indiana, western Kentucky, and northern Tennessee is in descending order: Louisville limestone, Waldron shale, Laurel limestone, Osgood shale and limestone, and Brassfield limestone.

The most northern localities at which these formations have been identified have been indicated on preceding pages. Southward they can be traced in an almost continuous series of outcrops as far as Raywick, 10 miles west of Lebanon, Kentucky. Then, after an interval of 80 miles in a southwesterly direction, they reappear in the vicinity of Lafayette, Bledsoe, and South Tunnel, in Macon and Sumner counties of northern Tennessee. In the intermediate areas these Silurian strata are covered by Devonian and later deposits.

28. Brassfield limestone

In 1904 Foerste published a map of southeastern Indiana showing the variations in thickness of the Brassfield limestone in southeastern Indiana. In Wayne, Union, and Fayette counties this limestone thins out westward, rarely exceeding 8 feet in Fayette and Franklin counties, and usually equalling less than 5 feet farther south, as far as the area east of Louisville. The Brassfield limestone is entirely absent in two areas in adjacent parts of Ripley, Jennings, and Decatur counties, between New Marion, Butlerville, and Westport, and, surrounding these areas, the basal part of the Brassfield limestone contains more or less numerous pebbles.

The area within which the Brassfield limestone has a brownish color similar to that of smoked salmon extends from Laurel, Indiana, southward to Saluda creek, 4 miles south of Hanover. In this area it is granular and often fossiliferous. Rock of the same character reappears southeast of Charlestown, Indiana, and also in the area between Floydsburg and Cane Spring in Bullitt county, Kentucky.

In the area between the northwestern corner of Switzerland county, Indiana, and LaGrange, in Kentucky, the Brassfield usually is quite thin, has few fossils, and is of a light red or pink color.

South of Cane Spring, near the southern margin of Bullitt county, as far as Raywick, 10 miles west of Lebanon, the Brassfield formation increases in thickness, is white in color, and frequently is cherty.

29. *Osgood formation*

The Osgood formation in southern Indiana consists of the following members in descending order: Upper Osgood clay, Osgood limestone, Lower Osgood clay, Basal limestone.

The basal limestone usually varies between 8 and 15 inches in thickness, occasionally equals 24 inches, and rarely attains 32 inches. It usually is light in color, but may have a reddish or brownish tint. Fossils are rare, and not diagnostic.

The overlying Lower Osgood clay varies usually between 7 and 16 feet in thickness, the smallest thickness, 3 feet, found near Napoleon, and the largest, 14 to 16 feet, recorded from the area east and northeast of Madison and thence as far north as the southern part of Ripley county. In a general way the evidence favors a thinning of this Lower Osgood clay, in southern Indiana, in a direction westward or toward the areas in which the Brassfield limestone is absent, but more numerous data are necessary to make this conclusion convincing.

In Clark and Jefferson counties, this Lower Osgood clay usually is a soft clay or shale. Along Big Creek, the upper half of this clay becomes a somewhat harder, more indurated clay rock. Farther north, on Otter Creek, this clay rock contains irregular masses of rubbly limestone, and still farther north this upper half of the clay section consists altogether of rubble limestone. At the same time the lower half of the Lower Osgood clay becomes strongly indurated, so as to form a hard clay rock. Finally, in Franklin and Fayette counties, the entire Lower Osgood clay section consists of fairly well bedded limestone, but softer and thinner bedded than the overlying part of the Osgood section which is supposed to

correlate with the typical Osgood limestone of more southern areas. In the two counties named these softer limestones are only about 4 feet thick.

The Osgood limestone member usually varies between 3 and 5 feet in thickness. It usually is granular in structure, and often is richly fossiliferous, especially in Ripley county and in the northern and eastern part of Jefferson county. The most southern locality at which fossils are abundant is at Harrod Creek, about 5 miles northeast of Louisville, on the Kentucky side of the Ohio River. Fossils in the area indicated occur not only in the Osgood limestone but also in the adjacent parts of the immediately overlying and underlying clays. Farther north, in Franklin and Fayette counties, where the Osgood limestone becomes an inferior, dense grained, whitish limestone, fossils are very scarce.

The Upper Osgood clay varies usually from 2 to 5 feet in thickness in the southern half of Ripley and Jennings counties, and thence southward as far as the Ohio River. Northward, however, this clay rarely exceeds one foot in thickness, and frequently it is reduced to only a few inches. It is assumed to be represented by the soapstone at the top of the Osgood formation in Franklin and Fayette counties.

In western Kentucky all three divisions of the Osgood formation can be followed readily as far south as Marion county. In this area both the Lower and the Upper Osgood clay are relatively soft, as in the more southern counties of Indiana. In Jefferson county the total thickness of the Osgood is about 30 feet.

30. Laurel limestone

The total thickness of the Laurel limestone can be determined only where it is overlaid by the Waldron shale, and few localities occur where both the Waldron and the top of the Osgood formation are present. At St. Paul, in the southeastern part of Shelby county, Indiana, its thickness is about 48 or 50 feet. In Clark county, in the southern part of the state, a thickness of 60 feet was estimated at the Tunnel Mill, about 2 miles northeast of Charlestown, 40 feet at the Charlestown Landing, and 50 feet on Bull Creek nearly 2 miles southeast of Hibernia, but all of these

measurements in Clark county were made where the contacts with the underlying and overlying strata were not clearly defined.

At St. Paul, the lower 17 feet of the Laurel formation supplies excellent building stone: above this are 25 feet which are not well bedded, and are cherty at top and bottom. The upper part, 7 feet thick, is crinoidal and has supplied the numerous fossils found in the Laurel limestone in the vicinity of St. Paul. This fossiliferous crinoidal rock apparently can be traced as far southward as the exposures near Big Creek several miles southeast of Dupont, in the northwestern part of Jefferson county.

In western Kentucky the Laurel limestone can be found at numerous exposures as far south as the southern part of Nelson county, beyond which it is covered by Devonian and later deposits. In Jefferson county its thickness ranges from 35 to 40 feet.

31. Waldron clay

The Waldron clay shale in Clark and Jefferson counties of Indiana varies usually between 4 and 10 feet in thickness, though a thickness of 14 feet is recorded from a locality about 2 miles southeast of Dupont, in the northwestern part of Jefferson county, and one of 20 feet is doubtfully recorded from a locality on Camp Creek, 2 miles east of New Washington. Farther north its thickness usually does not exceed 6 feet, thinning to 1 or 2 feet at its most northern exposures.

In Jefferson county, Kentucky, its thickness varies between 10 and 15 feet. It may be traced southward until it becomes covered by Devonian and later strata in Nelson county.

It is richly fossiliferous in localities of limited extent, located in Shelby, Bartholomew, Jennings, and the northwestern part of Jefferson counties in Indiana. Fossils are few at this horizon in western Kentucky but are abundant again at Newsom, 17 miles southwest of Nashville, Tennessee.

32. Louisville limestone

The name Louisville formation, as a stratigraphic term, was introduced by Foerste in 1897 for that part of the Niagaran formation which overlies the Waldron in the vicinity of Louisville.

Kentucky, and in the adjacent part of Indiana. Butts records a thickness of 90 feet as penetrated by a well at Buechel, 8 miles southeast of Louisville, and estimates its total thickness in that area as at least 100 feet. The maximum thickness exposed along Beargrass Creek in the eastern part of Louisville is 63.5 feet, but here the basal part of the Louisville formation is not exposed. The thickest exposure of the Louisville formation known in southern Indiana is at Charlestown Landing, 2.5 miles southeast of Charlestown, in Clark county, where it is 67 feet thick, its lower part, for a thickness of 17 feet, consisting of what is known locally as the lime rock. About a mile upstream along the Ohio River the Louisville formation is 55 feet thick. A mile and a half farther upstream, where the Louisville formation is 45 feet thick, the lower 20 feet of this section is formed by the lime rock. The Louisville formation continues to become thinner toward Hanover and Madison, the most eastern exposures occurring north of Madison. The formation evidently thins out eastward toward the crest of the Cincinnati anticline.

The Louisville formation thins out also toward the north. At Paris Crossing, 14 miles northwest of Madison, it is about 25 feet thick. At Hall's famous fossil locality on Conn Creek, south of Waldron, in the southeastern part of Shelby county, it is 8 feet thick. It has not been identified with certainty at Milroy, in the southern part of Rush county. It is absent at Greensburg. Whether it thickens westward from St. Paul, under cover of the overlying Devonian strata, has not been determined but appears probable.

The lime rock forming the lower 20 feet of the Louisville formation along the Ohio River in southern Indiana and northern Kentucky is a white limestone which formerly was used as a building stone and also for the manufacture of lime. The overlying part of the formation usually weathers to a light or medium brown. At Beggs Run, 2.5 miles northeast of Charlestown Landing, this lime rock contains *Pentamerus* cf. *oblongus*, and this species occurs also in great abundance in the lower strata in the area east and southeast of Louisville.

Along a branch of Lick Run southeast of the depot at Charles-

town, where the total thickness of the Louisville formation is 67 feet, *Astraeospongia meniscus* with well preserved spicules occurs about 22 feet below its top, or about 25 feet above the lime rock. *Rhipidium nysius* occurs at the top of the formation 1.5 miles north of Utica, and *Pentamerus cylindricus* is found 25 feet below its top on the high land southwest of the mouth of Fourteen-Mile Creek, about 25 feet above the lime rock. In the Louisville area the species of *Conchidium* at present included in *Rhipidium* occur distinctly above the horizon at which *Pentamerus* cf. *oblongus* is common.

Although 200 species of fossils have been identified, described, or figured from the Louisville limestone in the Louisville area, almost all of these have come from the upper part of the Louisville formation. Nettelroth, in his description of brachiopods and other shells, refers only 9 species to the lower Niagaran, in the area east of Louisville. Of course, some of the latter may have come from horizons beneath the Louisville formation. W. J. Davis, in his figures of Silurian corals from the Louisville area includes 83 species. One of these, *Lindstroemia gainesi*, is from the Brassfield formation. Three species, *Streptelasma patula*, *Zaphrentis socialis*, and *Zaphrentis patens*, are from the vicinity of Brunerstown.

One specimen of *Thecia major* was cited from 25 feet below the top of the Louisville formation. *Favosites niagarensis*, *F. forbesi*, *F. spongilla*, and *F. louisvillensis* are not cited from any particular horizon within the Niagaran. All of the other species are listed either from the reddish or ferruginous clay at the top of the Louisville formation in the Beargrass Creek region or from the immediately underlying white clay, which ranges at various exposures from 2 to 10 feet beneath the top of the Louisville.

The reference of nearly all the Silurian corals to the top of the Louisville formation in the Louisville area is due to several causes. Obviously, corals are abundant here; but, still more obviously, the white and reddish clay at the top of the Louisville formation permitted the collecting of specimens free from the matrix, ideal for purposes of illustration. Corals occur also at other horizons within the Louisville formation, but here they are of more local

distribution, occur at irregular intervals, and usually they can not be cleaned readily from the matrix. They have been found in fair numbers as low as the layers immediately above the *lime rock* mentioned in the preceding lines. No attempt has been made by anyone so far to determine the vertical range of either the corals or of the other groups of fossils in the Louisville area in such a manner as to secure an insight as to their value for discriminating the lower, middle, and upper parts of this formation in the type area.

Southward from Louisville, the Louisville formation can be traced as far south as the southern part of Nelson county, where it passes under the cover of Devonian and later formations. It reappears in the vicinity of Bledsoe, 12 miles northeast of Gallatin, in northern Tennessee.

Unfortunately it is not known from what exact horizon the species *Anisocrinus greenei*, *Macrostylocrinus meeki*, *Troostocrinus reinwardti*, *Caryocrinites kentuckiensis*, *Dimerocrinus halli*, and *Gissocrinus lyoni* were obtained in the Louisville formation, since the first three of these species occur also in the Beech River formation of the Brownsport group in western Tennessee, and the last three at least have close relatives in the latter.

I. ISOLATED BRASSFIELD EXPOSURES IN KENTUCKY

33. *Central Kentucky*

Isolated exposures of Brassfield limestone occur also at several localities in south-central Kentucky.

One of these is located on Scrub Grass Creek, 3 miles southwest of Mitchellsburg, in Boyle county. This exposure is located about half way between the most western exposure of the Brassfield on the eastern side of the Cincinnati anticline, near Stanford, and the most eastern exposure on the western side of this anticline in the vicinity of Raywick, 10 miles west of Lebanon. Here the Brassfield is exposed with a thickness of 15.5 feet, the top layer, one foot thick, containing *Stricklandinia triplesiana*, an undetermined species of *Whitfieldella*, and the large crinoid beads so characteristic of the top of the Brassfield all along the eastern side of the Cincinnati anticline in Ohio and Kentucky. The affiliation

of this outcrop is with the exposures as known on the eastern side of this anticline, though there may have been a connection, across the crest of the anticline, with the exposures on the western side of the anticline, the gap between Scrub Grass Creek and the nearest exposures of the Brassfield in the Raywick area being only about 23 to 25 miles.

34. Cumberland River

The Brassfield limestone occurs also at three localities on the Cumberland River; one along Fishing Creek 5 miles directly west of Somerset. Here the massive limestone forming the lower part of the formation is 7 feet thick. The overlying distinctly bedded limestones equal 10 feet. The top of the formation is formed by a layer of limestone one foot thick, containing *Whitfieldella subquadrata*, *Calymene vogdesi*, and the large crinoid beads characteristic of the top of the Brassfield on the eastern side of the Cincinnati anticline, farther north. The thickness of the overlying clay shales belonging to the Crab Orchard division of the Silurian can not be determined, though exposed for fully one mile up the creek.

The Brassfield limestone is exposed also 8 miles west of Fishing Creek, at the lower end of Forbush Creek, at the northern corner of Wayne county. Here its thickness is 15.5 feet, a layer with large crinoid beads occurring 21 inches below its top, associated with *Whitfieldella subquadrata*.

About a mile down the river, at the mouth of Little Cub Creek, the Silurian limestone is 19 feet thick and is overlaid by 2.5 feet of clay shale, 2 feet of argillaceous limestone, and an interval of 9 feet probably occupied by clay shale. At 3.5 feet below the top of the continuous limestone section the rock contains the large crinoid beads and *Whitfieldella cylindrica*. This limestone section is correlated with the Brassfield. The overlying clay and argillaceous limestone is referred to the lower part of the Crab Orchard group.

The same kind of large crinoid beads, accompanied by *Stricklandinia triplesiana*, is reported by Butts from the Brassfield part of the Red Mountain formation of the Birmingham area of north-

central Alabama. This is a distance of 450 miles from Dayton, Ohio, where these fossils were observed first. It suggests a faunal connection of these two areas along the eastern side of the Cincinnati anticline in Brassfield times which continued into the Lower Clinton at least, and which may have extended to the Upper Clinton.

The crest of the southern extension of the Cincinnati anticline passes through Limestone county, in the northern part of Alabama. West of this county, in the valleys of Shoal and Bluewater creeks in the north-central parts of Lauderdale county, Silurian strata similar to those in the vicinity of Iron City, in the southwestern corner of Lawrence county, Tennessee, occur. East of Limestone county, in the northern part of Madison county, Alabama, Butts found *Favosites favosus* and *Halysites* cf. *microporus* 4 miles west of New Market, in a gray limestone of which 8 feet was exposed immediately beneath the Chattanooga Black shale above stream level. Farther southeast, in the valley passing through Scottsboro, Guntersville, and southwestward, only the eastern clastic phase of the Brassfield has been identified. Farther eastward, in the region of Birmingham, this clastic phase of the Brassfield formation is overlaid by similarly clastic phases of the Lower and Upper Clinton. Just where the exposure of Silurian limestone west of New Market fits into the general section as exposed in the Birmingham area is unknown, but large celled forms of *Favosites*, identifiable as *Favosites favosus*, as not known from the Brassfield, but are known in the Dayton limestone of Ohio, and occur also in overlying Niagaran formations.

J. SILURIAN OF NORTHERN TENNESSEE

35. *Louisville limestone*

The sequence of Silurian strata characteristic of southern Indiana and western Kentucky may be recognized also in northern Tennessee, in Macon, Sumner, and Davidson counties.

The only locality at which the Louisville formation can be identified with any degree of certainty is at Bledsoe, 13 miles northeast of Gallatin. Here there is a complete sequence extending from the Louisville downward to the Brassfield. The Louis-

ville formation at this locality is 82.5 feet thick, and is overlaid directly by the Chattanooga Black shale. *Pentamerus* cf. *oblongus* occurs at approximately 20 and 50 feet above the base of the Louisville formation, while *Rhipidium knappi* occurs at elevations of 60, 63.5, and 73.5 feet above its base. This is the relative position of these two species also in the Louisville area.

Pentamerus cf. *oblongus* is fairly common in the lower part of the Louisville formation along the Ohio River between Louisville and Charlestown, and also at Clermont in the southeastern part of Bullitt county, Kentucky. *Rhipidium knappi*, on the contrary, belongs to the upper third of the Louisville formation in the Louisville area. Among the other fossils found in the Louisville formation at Bledsoe are *Rhipidium nysius, Rhipidomella hybrida, Platystrophia* sp., *Cladopora reticulata, Coenites verticillatus,* and *Lyellia americana.*

The only other locality in northern Tennessee at which a fossil suggestive of the Louisville formation was found is at the bridge west of Pegram in the southern part of Cheatham county, 16 miles southwest of Nashville. Here the top of the Silurian section consists of 8 feet of calcareous clay shale containing *Calceola tennesseensis, Atrypa niagarensis,* and *Eospirifer foggi,* this horizon being identified by Bassler as Lobelville. Underlying this clay shale down to the level of the railroad track is a rather soft limestone. Beneath the track level the rock is more shaly. At these lower levels Bassler found several corals of species occurring also in the Lobelville clay shale at the top of the Silurian at this locality, but he fails to list these species. At the base of the Pegram bridge section Foerste found *Eospirifer foggi* in the bottom of a wetweather stream entering the Harpeth River from the north. Here it occurs in a hard limestone very different from anything known in the typical Lobelville. This limestone possibly is identical with that overlying the Waldron clay shale at the locality 3 miles west of Newsom described by Bassler, but proof of their identity still is lacking.

In the Louisville area *Eospirifer foggi* is characteristic of the upper third of the Louisville formation so that its presence in the

upper clay shales in the Pegram bridge section appears to warrant the reference of the Lobelville formation to the upper part of the Louisville as exposed in northern Kentucky. Possibly the limestone at the base of the Pegram bridge section also belongs to the Lobelville, but the evidence at present is insufficient. In a similar manner, it is in doubt whether the massive limestone overlying the Waldron shale 3 miles west of Newsom is to be correlated with the Lego limestone or with the Lobelville. Lithologically the correlation with the Lego limestone seems preferable, since no rock of this type is known in the Lobelville formation in its area of typical development. However, no paleontological evidence favoring this correlation is known at present.

The nearest exposure of formations belonging to the Brownsport group in the area southwest of Pegram is at Peeler Pond, 1 mile north of Whitfield, 8 miles west of Centerville. Here only the upper two formations, the Lobelville and Decatur, are exposed, the Lobelville consisting of clay shale interbedded with thin limestone in its upper part, while the overlying Decatur formation consists of a massive limestone. Massive limestones occur however, in the underlying Bob formation which is not exposed at the locality named.

Attempts to trace the Louisville limestone from its exposure at Bledsoe in northern Tennessee farther southwestward apparently indicate that the lower part of this limestone is exposed also at Baker station 13 miles north of Nashville in the northeastern corner of Davidson county; at Newsom 14 miles southwest of Nashville; the bridge west of Pegram 4 miles west of Newsom; Centerville 33 miles southwest of Pegram; and Montgomery Mill near the mouth of Piney creek and 6 miles northwest of Centerville. However, no limestone referable to the Louisville occurs at Peeler Pond one mile north of Whitfield and 8 miles west of Centerville. What becomes of this supposed Louisville limestone in the area southwest of Centerville requires further investigation. In a similar manner the possibility of a northeastward extension of the Lego limestone of New Era, Clifton, Cerro Gordo, and more southern localities requires consideration.

36. *Waldron clay*

The underlying Silurian strata are more readily followed. The Waldron clay shale is full of fossils at Newsom, and is fairly supplied with fossils at Whites Bend, 10 miles northeast of Newsom. It may be recognized westward on Leipers Creek, at Fly, 16 miles east of Centerville, also at Centerville, and Montgomery Mill; but southward of Centerville it can not be identified until the southern parts of Lewis and Perry counties are reached. The Laurel limestone can be identified in similar areas, since its recognition depends in part on the presence of the overlying Waldron clay. It usually is a whitish limestone, well bedded, and quarried locally.

37. *Osgood formation*

The Osgood formation changes considerably westward. West of Lafayette, and at Bledsoe, it is a clay shale. At South Tunnel this formation consists of indurated clay rock interbedded with shaly layers. At Baker station the lower part consists of soft clay shale but the upper part is indurated and crinoidal. At Whites Bend the upper part is more calcareous and grades upward into the Laurel. At Newsom the lower part is relatively soft clay rock while the upper part is more indurated. At Linton, about 5 miles south of Newsom, the lower part of the Osgood consists of argillaceous limestone, weathering readily, while its upper part is harder. Farther southwestward, at Fly and Centerville, the Osgood formation can be distinguished from the overlying Laurel limestone chiefly by its more ready weathering, both formations here consisting of limestone.

38. *Brassfield limestone*

West of Lafayette the Brassfield is a bluish limestone. At Bledsoe this limestone is whitish. At South Tunnel, Baker, Goodlettsville, and Newsom this limestone becomes cherty and in this chert are found *Triplecia ortoni* and *Stricklandinia triplesiana*. A specimen of the coral identified as *Ptychophyllum* cf. *ipomoea* was found at South Tunnel. These occur in association with less diagnostic fossils.

The Brassfield limestone thins out conspicuously from the vicinity of Newsom eastward as far as the area west of Lafayette; from 30 feet at Newsom to 3 feet at the most eastern exposure. The Osgood formation, on the contrary, thickens eastward, from 10 feet at Newsom to 22 feet west of Lafayette. The changes of the Laurel and Waldron in this region are less conspicuous.

K. SILURIAN OF WESTERN TENNESSEE

In western Tennessee the Louisville formation is replaced by the Brownsport group of Niagaran formations, and the Waldron, Laurel, Osgood, and Brassfield formations are difficult to identify locally.

39. Brassfield limestone

The Brassfield formation can be identified definitely at Clifton by means of its characteristic fossils: *Metapolichas clintonensis, Calymene vogdesi, Glyptodendron subcompressum, Cypricardinia* cf. *undulostriata, Cliftonia striata, Rhynchotreta simplex, Stricklandinia ? dichotoma, Stegerhynchus whitii praecursor*, and *Stegerhynchus neglecta cliftonensis*. Here the Brassfield is one foot thick and consists chiefly of chert with some limestone. Farther west, at Swallow Bluff, it consists of limestone 18 inches thick, overlaid by black chert 2 to 8 inches thick. At Glenkirk, 3 miles north of Clifton, the massive white limestone at the base of the Silurian section contains *Illaenus daytonensis* and is almost 4 feet thick. Farther north, at New Era, the limestone identified as Brassfield is 20 feet thick. Its lower and middle parts are more crinoidal. Its upper third is more dense and when weathered has a greenish brown tint somewhat similar to that of the cherty limestone at Clifton, but it contains no fossils.

Along the upper parts of Horse and Beech creeks it has not been possible to distinguish the Brassfield from the Osgood, nor the latter from the Laurel. The best exposures here are at Maddox Mill 5 miles southeast of Savannah, and on Beech creek 3.5 miles northwest of Waynesboro.

At Cedar Point, one mile north of Iron City, there is a coarse-bedded ferruginous limestone 2.5 feet thick which formerly was

mined. It is overlaid by cherty rock from 2 to 12 inches thick, containing *Platymerella manniensis*, *Stricklandinia? dichotoma*, *Triplecia ortoni*, and *Illaenus daytonensis*. At Riverside this coarse limestone is strongly cross-bedded, massive, nearly 6 feet thick, and contains *Platymerella manniensis* and *Stricklandinia? dichotoma*. Two miles south of Iron City, at Pruitton, Alabama, Silurian is exposed, presumably a continuation of that exposed at Iron City.

40. Osgood formation

Southwest of Centerville, in the vicinity of New Era and Glenkirk on the Tennessee river, north of Clifton, the strata identified as Osgood consist of a soft reddish limestone from 6 to 12 feet thick, overlaid by a harder limestone, 3 feet thick, also tinted with red, which appears to be transitional to the still harder Laurel limestone farther up. At Clifton, that part of the section which is identified as Osgood is 14 feet thick and consists of comparatively thin-bedded layers of reddish argillaceous limestone, overlaid by harder reddish-purple layers referred to the Laurel. Near the middle of the Osgood formation there are several layers which contain very large and coarse crinoid stems in addition to *Lechritrochoceras cinctutum*, *Hyolithes cliftonensis*, *Diaphorostoma cliftonensis*, *Platyceras pronum*, and *Orthostrophia tenax*. Large specimens of orthoceroids occur at all levels within the Osgood, as usual at this horizon in the central and southern part of western Tennessee. At Clifton, *Pisocrinus gemmiformis* and *Stephanocrinus osgoodensis* continue from the upper part of the Osgood into the lower part of the Laurel, as at many localities in southern Indiana.

At Swallow Bluff, west of Clifton, the rock identified as Osgood consists of hard, massive, white limestone 8.5 feet thick, overlaid by thin-bedded white limestone 9.5 feet thick and this by softer argillaceous rock tinged with red, 5.25 feet thick. The lower part of the overlying Laurel here is white, but its middle and upper parts are more reddish-purple, as at Clifton. Farther south, at Cerro Gordo, Cave Spring, Iron Bridge, Maddox, and Dodds, along Horse creek, the Osgood, Laurel, and Waldron horizons are

not readily distinguishable lithologically and appear to form an almost continuous series grading up into the limestone regarded as of Lego age. This is true also on Beech creek, 3.5 miles northwest of Waynesboro. At Iron City, only 3 feet of argillaceous limestone, weathering more readily than the overlying rock, is referred to the Osgood. North of the railroad bridge at Riverside, the limestone immediately above the cross-bedded Brassfield contains *Pisocrinus gemmiformis* and one specimen of *Holocystites* of the Osgood type, 4 inches long, and apparently indicative of the Osgood horizon, though the Osgood here apparently grades into the overlying Laurel, as elsewhere in the southern part of western Tennessee.

41. Laurel limestone

As in other parts of western Tennessee, the rock identified as Laurel in the area south of Centerville consists merely of those harder limestones which form a continuous series between the softer argillaceous Osgood limestones at the base and the Waldron clay shale at the top. Locally, where the Waldron can not be identified, the Laurel limestone appears to merge with the overlying Lego limestone. This appears to be true at several localities along Horse creek, in Hardin county.

42. Waldron clay

The identification of the Waldron horizon at Iron City is based on the presence of *Hyolithes newsomensis* and *Sowerbyella tennesseensis,* species occurring also at Newsom and Swallow Bluff. *Sowerbyella tennesseensis* occurs also in the Waldron of New Era and Clifton. *Stephanocrinus tennesseensis* occurs in the Waldron at New Era, Clifton, Swallow Bluff, and Iron City. Among less widely ranging species, *Delthyris swallowensis* occurs at Swallow Bluff, *Eucalyptocrinus elrodi* and *Eucalyptocrinus magnus* are known from Clifton and also from Newsom, the former occurring also in the Waldron of southern Indiana.

The white limestone overlying the Waldron horizon in southern Tennessee is correlated tentatively with the Lego limestone of the more central parts of western Tennessee.

43. *Lego limestone*

In western Tennessee, in the southern parts of Perry and Decatur counties and the northern parts of Wayne and Hardin counties, two formations intervene between the top of the Waldron shale and the base of the typical Brownsport group of formations. In ascending order these are the Lego limestone and the Dixon clay.

In 1903 the name Lego limestone was proposed by Foerste for that part of the Silurian section in southwestern Tennessee which immediately overlies the Waldron clay shale. It usually varies between 30 and 45 feet in thickness and is overlaid by 30 to 45 feet of red clays to which the name Dixon clay was given. Lithologically the middle and lower parts of the Lego limestone resemble those forming the upper part of the Laurel limestone so closely that they are difficult to distinguish where the intervening Waldron clay is not exposed.

The type locality for the Lego limestone is at New Era, less than 2 miles south of Lego. Here the lower part of the formation, 22 feet thick, is formed by whitish limestone, overlaid by alternating whitish and reddish limestones 10 feet thick, the total thickness of the Lego limestone being 32 feet. At Glenkirk its thickness is 36 feet. At Clifton it is 46 feet, the limestone layers being cracked irregularly, its upper third including layers of argillaceous reddish limestone. At Cerro Gordo the upper part of the Lego limestone is exposed for a thickness of 28 feet. Farther south usually there is a transition between the Lego limestone and the Dixon clay so that it is impossible to draw an exact line between them.

In its typical area of exposure the Lego limestone contains scarcely any fossils, the few found so far being poorly preserved and not diagnostic.

At the time these Lego limestones were studied more than thirty years ago it seemed possible that they might correspond stratigraphically with that part of the Silurian section west of Pegram which contains *Spirifer foggi*. This horizon occurs beneath the level of the railroad, in the bed of a wetweather

stream, north of the bridge. Unfortunately it is not known how far below this horizon at Pegram the Waldron shale is located, and no fossils have been found in the typical Lego limestone confirming such a correlation.

44. *Dixon clay*

The name Dixon clay was proposed in 1903 by Foerste for that part of the Silurian section in southwestern Tennessee which immediately overlies the Lego limestone and underlies the strata there included in the Brownsport series. Exposures of both the Dixon clay and of the Lego limestone are common within 2 miles of Dixon Spring, 4 miles east of Decaturville. At New Era, 7 miles southeast of Dixon Spring, the Dixon red clay is 37 feet thick. It is partly indurated and dark brick-red in color, the base of the Brownsport series being formed by a white clay layer 2 feet thick. At Glenkirk the Dixon clay is 22.5 feet thick. At Clifton its thickness is estimated at 44 feet. At Cave Spring, near Cerro Gordo, the red clay immediately beneath the Brownsport series and 35 feet thick is referred to the Dixon clay. At the Sulphur Spring, 7 miles southeast of Savannah, the Dixon bed is 35 feet thick. Half a mile north of Martin Mill, on Indian Creek, it is 44 feet thick. At all of these localities the Dixon clay is overlaid by a whitish clay forming the base of the Brownsport series. The red phase of the Dixon formation is not known anywhere east of a line connecting Linden with Martin Mill. Even in the Tennessee River valley the red color is due chiefly to weathering. In less weathered sections, exposed by rapidly cutting streams, the red layers frequently alternate with white colored ones, the latter sometimes exceeding the former. The clay southward becomes more calcareous and argillaceous limestones make their appearance. The change from white limestone of the Lego limestone to the red clay of the Dixon formation takes place at different horizons at different localities. It is possible that east of the line connecting Linden with Martin Mill the Dixon clay may change to a limestone, but, in the absence of adequate fossils, this can not be determinal with confidence. *Fistulipora hemispherica* is the only fossil found in abundance at this horizon.

Pisocrinus tennesseensis occurs near its top. Both species range upward into the Brownsport. In fact, the Dixon formation may be the incipient stage of the Brownsport group, but the most characteristic fossil of that group, *Astraeospongia meniscus*, has not been found in the Dixon so far.

45. *Brownsport group*

The term Brownsport bed was proposed by Foerste, in 1903, for that part of the Silurian section in western Tennessee which lies above the Dixon clay shale and is overlaid by the Linden formation, or, in the absence of the latter, by the Hardin sandstone. It was intended to indicate this by the various sections published on pages 579, 580, 581, and 582 of the original publication (Journal of Geology, volume 11, 1903). The discussion of the Brownsport bed forms section III of the discussion of the Silurian Strata in the Tennessee River Valley, and includes pages 569–576, and also page 583. Here the Brownsport bed is discussed under divisions 7, 8, 9, and 10, of which sections 8 and 10 are of special significance.

The inclusion of strata of Decatur age within the Brownsport bed is indicated on page 571 by the statement: "At Perryville the upper part of the Brownsport bed is quarried. *Astraeospongia meniscus* occurs at the top, immediately beneath the Linden limestone." See also section 21 on page 581, and the first paragraph on page 426 of Bassler's paper on the Late Niagaran Strata of West Tennessee (Proc. U. S. National Museum, vol. 34, 1908).

The inclusion of the Gant bed as a part of the Brownsport is shown by the first sentence under division 10, on page 575: "Three localities belonging to the Brownsport horizon were referred by Professor Safford with some hesitation to the Helderbergian or Linden limestone. These are Bath Springs, the Colonel Smith locality, and the A. B. Gant locality." Moreover, in the list of Brownsport fossils on pages 708-714, 23 species are listed definitely from this Gant bed.

In a general way, the term Brownsport was intended to include those Niagaran strata which contain *Astraeospongia meniscus*, this being the most characteristic of the long ranging fossils occur-

ring in the Brownsport bed. Unfortunately, the underlying Dixon clay and Lego limestone are so nearly unfossiliferous that little is known of their relationship. The few species found so far in the Dixon clay admit of the idea that this clay may be the introduction of the Brownsport sequence.

A great step forward in our knowledge of the stratigraphy of the Brownsport strata was made in 1908 by Pate and Bassler when they divided the series formerly included under the term Brownsport bed into 4 formations. These, in ascending order, are the Beech River, Bob, Lobelville, and Decatur formations. Moreover, faunal subdivisions are proposed for each of the first three of these formations. In descending order these formations and their subdivisions are:

D. Decatur formation
C. Lobelville formation
  Coral zone
  Bryozoan zone
B. Bob formation
  Conchidium zone
  Dictyonella zone
  Uncinulus zone
A. Beech River formation
  Eucalyptocrinus zone
  Troostocrinus zone
  Coccocrinus zone

Owing to changes in nomenclature, the generic name *Conchidium,* in the preceding list of faunal zones, should be changed to *Rhipidium,* and the generic name *Coccocrinus* to *Lyonicrinus.*

46. Beech River formation

All the faunal zones of the Beech River formation are well represented in Perry, Decatur, and parts of Wayne and Hardin counties. The Uncinulus and Dictyonella zones of the Bob formation are reported from the same counties, but from fewer localities. The Conchidium zone, however, is recorded only from Perry and Decatur counties and is known only from a few localities. Most of the recorded exposures of the Lobelville formation are from Perry and Decatur counties, though occurring also in

Hickman and Hardin. The coral zone has been identified more frequently than the bryozoan zone. The Decatur formation is recorded most frequently from Perry and Decatur counties but has been identified also in Hickman county. The topography of the country evidently is a factor in the frequency of the outcrops recorded, but some of the faunal zones appear of more local distribution than others.

The Beech River formation was named after a river which enters the Tennessee River at a point about 3 miles north of Clifton in a direct line. Numerous outcrops of this formation occur in the general area between Perryville and Clifton, especially between Perryville and Brownsport Furnace and at numerous localities along Beech River. Pate and Bassler describe sections at Clifton, Brownsport Furnace, Decaturville, and at Lady's Bluff and Mousetail, the last two being in Perry County, but the section found at the glade 2 miles south of Perryville is regarded as the one best exposed and most clearly defined. Here the formation consists almost exclusively of shale weathering into a white clay. This is the formation which has furnished most of the crinoids described by Springer from the Brownsport group of southwestern Tennessee; they are most abundant in the upper or Eucalyptocrinus zone. *Troostocrinus reinwardti* is most abundant in the upper part of the middle or Troostocrinus zone of the Beech River formation and *Lyonicrinus bacca* is most abundant near the middle of the lower or Lyonicrinus zone of Pate and Bassler. The total thickness of the Beech River formation varies between 50 feet at Brownsport Furnace and 100 feet at Clifton.

Astraeospongia meniscus is most abundant in the Beech River formation though occasional specimens are found at the extreme top of the Decatur formation at the top of the Brownsport group. *Astylomanon cratera, Caryomanon incisolobatum* and *Caryomanon stellatimsulcatum* are likewise abundant and range through all three zones.

Anisocrinus greenei, Macrostylocrinus meeki, and *Troostocrinus reinwardti* occur both in the Beech River formation of southwest-

ern Tennessee and also in the Louisville formation of Louisville, Kentucky. Unfortunately their exact horizon within the Louisville formation is unknown, but it is assumed to be in its upper third.

47. *Bob formation*

In the Bob formation the limestones dominate. At the few localities at which its total thickness is recorded this equals from 35 to 40 feet. While of wide distribution it is not recorded from Decaturville, Perryville, or Mousetail in Perry County, and evidently is absent locally also elsewhere where the Beech River formation is followed directly either by the Lobelville formation or even by the *Decatur.*

The Bob formation was divided by Pate and Bassler into three faunal zones, named in ascending order the Uncinulus zone, the Dictyonella zone, and the Conchidium zone. The lower and middle zones have maximum thicknesses of 30 feet, the upper zone being 15 feet thick at Brownsport Furnace and Lady's Bluff.

Half a mile below Bob on the west bank of the Tennessee River the lower part of the *Uncinulus stricklandi* zone consists of red limestone and shale having a thickness of 20 feet, lithologically resembling the Dixon formation. These are overlaid by rather massive white limestone in layers 8 to 12 inches thick, totalling 10 feet, and also containing *Uncinulus stricklandi*, thus adding up to 30 feet for the entire zone. The overlying part of the Bob formation here is 30 feet thick and is referred to the *Dictyonella* zone. The lower half of this zone consists of yellow argillaceous limestone layers, 2 to 3 inches thick, alternating with soft yellow clay. Here brachiopods, including *Dictyonella gibbosa*, are common. These brachiopods range upward into the upper half of the zone which here consists chiefly of clay. The upper or Conchidium zone of the Bob formation consists of nodular, cherty limestone or indurated clay shale. On the east side of the Tennessee River it is known at Lady's Bluff and west of the river it occurs at Brownsport Furnace. It has been identified at few localities.

48. Lobelville formation

The Lobelville formation lies directly above the Bob formation, where the latter can be identified. Elsewhere it rests on the Beech River formation. This Lobelville formation is of wide distribution in southwestern Tennessee, especially west of the Tennessee River. Two faunal zones may be recognized, the lower one, the Bryozoan zone, having a maximum thickness of 30 feet, while the upper or Coral zone attains a thickness of 45 feet locally. Lobelville is on the west side of Buffalo River, 14 miles north of Linden. The lower part of the Bryozoan zone consists of red clayey shale, the upper part is formed by bluish shale. Both parts contain bryozoans and corals, though these are most numerous in the upper or bluish shale. The bryozoans dominate greatly, the corals being relatively few.

The overlying Coral zone consists chiefly of shale and thin bedded limestone, with corals so abundant that the identification of this horizon presents little difficulty. Species are numerous, including numerous species known in the Louisville formation of northern Kentucky and the adjacent part of Indiana from that part of the formation which overlies the lime rock, about 20 feet thick, at its base. Among these corals is *Calceola tennesseensis* known also from the upper part of the Louisville formation at Louisville, Kentucky.

49. Decatur formation

The uppermost division of the Brownsport group is the Decatur formation. This is the formation proposed by Pate and Bassler for the Niagaran strata immediately overlying the Lobelville formation. It exhibits this stratigraphic sequence at Rise Mill near Linden, and at Mousetail, both in Perry County, also at Peeler Pond, one mile northwest of Whitfield, in Hickman County. At Lady's Bluff, where the Coral zone of the Lobelville formation is absent, the Decatur formation rests directly on the lower or Bryozoan zone of the Lobelville. Where both the Lobelville and the Bob formations are absent, as at one and a half miles north of Decatur and at 2 miles south of Perryville, the Decatur rests

directly on the top of the Eucalyptocrinus zone of the Beech River formation.

The maximum thickness of the Decatur formation is about 70 feet. It consists of a massively, white, coarsely crystalline, crinoidal, magnesian limestone which becomes yellow and slightly shaly at its top. The presence of *Uncinulus stricklandi*, *Wilsonia saffordi*, *Pachydictya crassa*, *Glauconome* sp., and *Astraeospongia meniscus* indicates Niagaran affinities, the species last named being found at the top of the Decatur formation, immediately beneath the Linden limestone, at the quarry half a mile northeast of Perryville. Under these circumstances the reference of the Decatur formation to the basal part of the Cayugan appears to be in error unless a considerable part of the Brownsport be transferred to the Cayugan also.

L. CAYUGAN OF OHIO

50. Greenfield, Tymochtee, Put-in-Bay dolomites

The Bass Island group includes that part of the series formerly known as Monroan which lies beneath the Sylvania sandstone. Carman and Schillhahn regard this Sylvania sandstone as the basal part of the Lower Devonian, as exposed in northern Ohio. The Bass Island group is referred to the Cayugan division of the Silurian.

This Bass Island group is divided, in descending order, into the following members:

Raisin River dolomite
Put-in-Bay dolomite
Tymochtee shaly dolomite
Greenfield dolomite

The Greenfield dolomite is from 75 to 100 feet thick and is typically developed in southern Ohio, in the vicinity of Greenfield, in the northeastern part of Highland county. It is the only member exposed in Highland, Ross, and Adams counties, and an isolated exposure occurs on the south shore of the Ohio River at Vanceburg, Kentucky. Northward it reaches southeastern Michigan, in common with all the other members of the Bass

Island group. It is a well bedded dolomite including as characteristic fossils *Hindella rostralis* and *Leperditia ohioensis*, associated with *Leperditia angulifera*, *Camarotoechia hydraulica*, *Rhynchospira praeformosa*, and *Schuchertella hydraulica*.

The overlying Tymochtee dolomite is conspicuously more shaly. It is approximately 150 feet thick. The type locality is Tymochtee Creek in Crawford township, in Wyandot County, in northern Ohio. It extends to the southern margin of Fayette county, in that state, but has not been identified farther south. It contains two species mentioned as characteristic of the Greenfield dolomite, namely *Hindella rostralis* and *Leperditia ohioensis*, but both are represented only by specimens distinctly smaller than those found in the Greenfield dolomite.

The Put-in-Bay dolomite is exposed typically at Put-in-Bay on South Bass Island. It consists of a massive, brecciated dolomite interrupted beneath its middle by a distinctly bedded horizon, its total thickness being about 50 feet. In its northern extension it is characterized by *Schuchertella hydraulica*, *Delthyris ohioensis*, *Spirorbis laxus*, *Pterinea lanii*, a species of *Leperditia*, and *Eurypterus eriensis*.

Since *Eurypterus eriensis* is regarded by Bassler, in his Bibliographic Index of American Ordovician and Silurian Fossils, as identical with *Eurypterus microphthalmus*, from the top of the Manlius, a tentative correlation of the Put-in-Bay formation of northern Ohio with that New York formation seems possible. The most southern exposure of the Put-in-Bay formation appears to be near the eastern margin of Fayette county. Here, however, the identification is chiefly lithological, no recognizable fossils having been found.

No similar agreement is known between any species found in either the Kokomo or Kenneth formations of northern Indiana and any known from any division of the Bass Island group of western Ohio. Cumings regards the Kokomo as about of the same age as this group, and the Kenneth as probably correlatable with one of the Monroan divisions of the Monroan of Ohio and Michigan. If the identification of *Pentamerus pesovis* Whitfield from the Kenneth limestone is correct, then it should be remem-

bered that this species was described originally from Adams county, Ohio, where only the Greenfield dolomite is known.

M. EARLY DEVONIAN IN SOUTHERN OHIO

51. *Hillsboro sandstone*

The Hillsboro sandstone is exposed typically on the top of Lilley Hill on the eastern margin of Hillsboro, Ohio. Here it is a sheet deposit, originally possibly nearly 12 feet thick, resting on the top of the Lilley dolomite, here only 60 feet thick. At this locality the top of the Lilley dolomite has been gullied by erosion in post-Niagaran times permitting the drifting of the Hillsboro sand into the cavities. Similar exposures occur at Rhoads Corner, 3 miles northwest of Sinking Spring, where the sheet deposit of Hillsboro sandstone, 10 to 20 feet thick, rests on both the Lilley and the Greenfield dolomites. Cavernous deposits of Hillsboro sandstone within the Lilley dolomite occur here also. The next overlying formation in this part of Ohio is the Ohio Black Shale, of Upper Devonian age.

Lithologically the Hillsboro sandstone closely resembles the Sylvania sandstone of northern Ohio. Carman and Schillhahn suggest that this Sylvania sandstone was a possible source of the sand in the Hillsboro sandstone. Regarding the Sylvania sandstone as of early Devonian age, and knowing that the typical sheet form of Hillsboro sandstone rests on the Greenfield dolomite its age could be either Lower or Middle Devonian. At least, it is not Niagaran as formerly supposed.

N. CORRELATION

52. *Centerville formation*

The Centerville clay shale is known at present only from 3 widely separated localities in Ohio, on the eastern side of the Cincinnati anticline: Centerville, in the southeastern part of Montgomery county; Lawshe, 4 miles west of Peebles in Adams county; and West Union, 10 miles south of Lawshe. The exact thickness of this shale has not been determined but nowhere is it known to

exceed 4 feet. It occurs beneath the Belfast bed where the latter is present; otherwise, directly beneath the Brassfield. The presence of such species as *Brachyprion* sp., *Schuchertella subplana brevior*, *Rhynchotreta thebesensis*, *Whitfieldella* cf. *ovoides*, and *Dalmanites* cf. *limulurus* suggests definite Silurian affinities, though the lithological character of the clay shale is similar to that of the underlying Elkhorn member of the Richmond. The location of the Centerville clay beneath the Brassfield suggests its reference to the Alexandrian of Savage; more specifically, to the Edgewood member of the Alexandrian as exposed in Alexander, Calhoun, and Will counties in Illinois, and in Pike county, Missouri, though the faunal evidence accumulated so far is not sufficient for exact correlation.

53. Belfast zone

The Belfast argillaceous limestone extends from Hillsboro, Kentucky, northward to Todd Fork north of Wilmington, Ohio. Farther northward it has not been identified definitely. Fossils are scarce, excepting annelid teeth locally, but the presence of *Halysites catenularia* and *Platystrophia daytonensis* shows its Silurian affinities. It is regarded as a local phase of the basal part of the Brassfield formation.

54. Platymerella manniensis zone

In the quarry northeast of the railroad station at Lawshe, in Adams county, Ohio, *Platymerella manniensis* occurs in the basal part of the Brassfield formation, directly above its Belfast phase. This species was described originally from Riverside and Iron City, in the southern part of western Tennessee. Savage has identified it also in Jersey and Calhoun counties in southwestern Illinois and the adjacent part of Missouri, and also in Kankakee county in northeastern Illinois. The chief interest in its Ohio occurrence is due to its occurrence both on the east and west sides of the Cincinnati anticline, without any known connecting area, agreeing in this respect with the distribution of the Centerville-Edgewood fauna.

55. *Brassfield limestone*

The Brassfield formation is widely distributed in the east-central parts of the United States, occurring in southwestern Ohio, southeastern Indiana, both the eastern and western parts of Kentucky and Tennessee, and the northern half of Alabama. Originally it probably surrounded the Cincinnati anticline, though its connection around the southern margin of this anticline is concealed by later deposits in southern Alabama. In general the Brassfield faunas east and west of the anticline are identical, excepting that the number of species identified on its western side is less, and that on both sides fewer species occur southward. However, the layer at the top of the Brassfield which contains the large crinoid beads characteristic of this horizon along the eastern side of this anticline from Dayton, Ohio, to Birmingham, Alabama, is unknown west of this anticline. Almost all subsequent Niagaran deposits on the two sides of the anticline differ conspicuously, only the Waldron being known by typical species on both sides, though east of the anticline the Waldron fossils are known only from Greene county, Ohio.

Approximately the same horizon is exposed by the Sexton Creek limestone in southwestern Illinois and the adjacent part of Missouri, and by the Kankakee limestone in northeastern Illinois. In southern Ontario the faunas most similar to the Brassfield of Ohio are those of the Cabot Head shale and of the underlying Manitoulin dolomite, the bryozoans being more common in the shale though most species are common to both. Among the latter are *Hallopora magnopora* and *Homotrypa? confluens*. Among the brachiopods common to both are *Dolerorthis flabellites* and *Glyptorthis fausta*.

56. *Oldham limestone*

The Clinton formations of eastern Kentucky, in ascending order, are the Plum Creek clay, Oldham limestone, Lulbegrud clay, Waco limestone, Alger clay, Ribolt clay shale, and Bisher formation. Of these, the Plum Creek, Lulbegrud, and Alger clays are unfossiliferous.

The characteristic fossil of the Oldham limestone in east-central

Kentucky is *Stricklandinia norwoodi,* a species known elsewhere only at Birmingham, Alabama, where it occurs in the *Stricklandinia* zone, a short distance beneath the *Pentamerus* zone, the latter being regarded as equivalent to the Wolcott limestone of New York. This suggests that the Oldham limestone is of Lower Clinton age, but beneath the level of the Wolcott. Ornamentation similar to that of *Stricklandinia norwoodi* is shown by *Pentamerus corrugatus* Weller and Davidson in the lower part of the Hopkinton in Jones county, Iowa.

At the Rose Run mine 4 miles east of Owingsville, Kentucky, where *Stricklandinia norwoodi* is unknown, the strata there identified stratigraphically as Oldham furnished a single valve of an ostracod identified as *Zygobolba rectangula.* Since this species occurs in the lower part of the Lower Clinton at Hagan, Lee County, in southwestern Virginia, its occurrence at the Rose Run mine suggests the Lower Clinton age also of the latter locality.

57. Waco limestone

The Waco limestone of east-central Kentucky is known to be of Clinton age because it is younger than the Lower Clinton Oldham formation and older than the Upper Clinton Ribolt clay shale, but its horizon can not be fixed more closely since the Waco fauna is distinct from all other Clinton faunas known at present. However, one fact suggests a tentative reference to the Lower Clinton, and that is the close agreement between the geographical distribution of the Waco limestone and the underlying Oldham limestone, and the separation of these two limestones by only 13 feet of clay shale without any stratigraphic break. In the same manner, the much wider distribution of the Alger and Ribolt clay shales suggests that both are probably of about the same age, so that, if the Ribolt is of Upper Clinton age, the Alger probably also is of Upper Clinton age, though older than the Ribolt.

58. Ribolt shale

The Upper Clinton age of the Ribolt clay shale is indicated by its ostracod fauna, though other species also occur. At Ribolt,

10 miles west of Vanceburg, in Lewis county, Kentucky, the Ribolt contains *Anoplotheca* cf. *obsoleta*, *Brachyprion mundula*, *Camarotoechia congruens*, *Camarotoechia neglecta*, *Chonetes vetustus*, *Bucaniella trilobata*, *Dalmanites limulurus*, and *Liocalymene* cf. *clintoni*; associated with the ostracods *Mastigobolbina typus*, *Mastigobolbina triplicata*, *Mastigobolbina trilobata*, *Mastigobolbina glabra*, *Plethobolbina* sp., and *Zygosella vallata*. Half a mile west of Peebles, in Adams county, Ohio, the following additional species occur: *Schuchertella* cf. *subplana*, *Pterinea emacerata*, *Mastigobolbina arguta*, *Mastigobolbina modesta*, *Mastigobolbina punctata*, and *Plethobolbina typicalis*. These ostracods are characteristic of the middle part of the Upper Clinton as exposed in Virginia, West Virginia, Maryland, and Pennsylvania, representatives of this fauna occurring as far north as Clinton, New York.

59. Bisher formation

The upper Clinton age of the Bisher formation also is indicated by its ostracods. At the Crooked Creek quarry 4.5 miles south of Sinking Spring, in Adams county, Ohio, the upper third of this formation contains *Dizygopleura asymmetrica*, *Dizygopleura lacunosa*, *Dizygopleura loculosa*, *Dizygopleura symmetrica*, *Paraechmina spinosa*, and *Primitiella aequilateralis*. These are species occurring in the *Drepanellina clarki* zone of Ulrich and Bassler in central Pennsylvania and western Maryland, where they occur in the upper part of the Upper Clinton.

The Ribolt clay shale and the Bisher formation, both of Upper Clinton age, occur in Lewis county, Kentucky, and in Adams and Highland counties of Ohio, but have not been identified farther north than Hillsboro, in Ohio.

60. Osgood formation

The Osgood formation of southeastern Indiana and the adjacent part of Kentucky has been identified by Bassler as of Upper Clinton age, chiefly on the evidence furnished by the bryozoans. Of the 80 species of bryozoans found in the Rochester shale in New York, Bassler identified 33 also in the Osgood of Indiana and but 14 in the Waldron of that state. After weeding out the wide-

ranging species of bryozoans, the evidence in favor of the contemporaneity of the Rochester and Osgood becomes greater. While practically all of the Osgood bryozoans occur also in the Rochester, the Waldron, on the contrary, contains many that are unknown in the Rochester.

While both the Bisher and the Osgood formations are of Upper Clinton age, they differ greatly from each other. The abundant and varied cystid fauna of the Osgood has no parallel in the Bisher fauna on the eastern side of the Cincinnati anticline.

61. Dayton limestone

In Adams county, Ohio, half a mile west of Peebles, *Pentamerus peeblesensis* is abundant in the Dayton limestone and sporadic specimens have been found as far north as Dayton, Ohio. On the basis of this single species, the Dayton limestone is regarded as of Lower Clinton age, possibly corresponding to the Pentamerus horizon at the top of the Lower Clinton in the Birmingham area of Alabama, but the Dayton limestone is not known south of Lewis county, in northern Kentucky.

62. Lilley formation

In Highland and Adams counties of southern Ohio the Lockport division of the Niagaran is represented by the Lilley and Peebles formations.

The Lilley formation is correlated tentatively with the Louisville formation, chiefly on account of the presence of *Strombodes striatus*, *Plasmopora follis*, and *Coenites verticillatus*, but this correlation requires further study.

63. Peebles dolomite

The upper half of the Peebles dolomite is correlated with the Guelph of southern Ontario, the northwestern part of Ohio, and southeastern Wisconsin, chiefly on account of the presence of *Megalomus canadensis*, *Trimerella acuminata*, *Trimerella grandis*, *Trimerella ohioensis*, *Pycnostylus elegans*, *Pycnostylus guelphensis*, and various gasteropods characteristic of the Guelph of these more northern areas Since search has revealed no Cedarville

fossils in the lower part of this Peebles dolomite it is assumed that this lower part also belongs to the Guelph. It is assumed also that the Peebles formation connects northward with the Guelph of northwestern Ohio, overlapping the Cedarville dolomite east of its present known area of outcrop, and thence connects with the Guelph of southeastern Wisconsin, possibly through southern Michigan.

64. Osgood, Laurel, and Massie formations of Ohio

In southwestern Ohio, in the area extending from Clinton county northward to Clark, and westward to Preble and Darke counties, the sequence of Niagaran formations in ascending order is: Dayton limestone, Osgood clay, Laurel limestone, Massie clay, Euphemia dolomite, Springfield dolomite, and Cedarville dolomite.

The Osgood and Laurel formations are developed typically in southeastern Indiana, and their identification farther eastward, in Ohio, is based merely on stratigraphical and lithological evidence, no characteristic species being known in the Ohio area. The Osgood forms the top of the Clinton division of the Niagaran in this area, while the Laurel forms the base of its Lockport division. The Massie clay at Cedarville, Ohio, contains a typical Waldron fauna.

65. Euphemia, Springfield, and Cedarville dolomites

Passing the Euphemia and Springfield dolomites for a moment, the Cedarville fauna closely resembles that of the typical Racine of southeastern Wisconsin and adjacent Illinois, numerous species, including crinoids and some cystids as well as other groups of fossils, being identical in the two areas. The underlying Springfield and Euphemia dolomites may correlate with parts of the Waukesha dolomite of southeastern Wisconsin, but no fossil evidence warranting such a correlation is known at present. It is assumed that the Cedarville connected with the Racine through some area passing north of the present area of outcrop of the typical Huntingdon dolomite. It is assumed also that the Cedarville dolomite, east of its present known area of outcrop, is overlaid by the Guelph, thus connecting the Peebles dolomite of

southern Ohio with the typical Guelph of Ontario and northwestern Ohio.

66. Osgood, Laurel and Waldron of Indiana

In southern Indiana, western Kentucky, and northern Tennessee, the Lockport division of the Niagaran consists of the following formations in ascending order: Laurel limestone, Waldron shale, and Louisville limestone. Of these, the Waldron appears to contain the continuation of the Brassfield and Osgood faunas, interrupting the Laurel-Louisville sequence which has a somewhat different origin.

The Laurel formation of Indiana appears to be related to the Joliet formation of northern Illinois and the Lower Hopkinton of Iowa. The cephalopods *Elrodoceras indianense* and *Gigantoceras elrodi* from the Upper Laurel are represented in the Joliet formation either by identical forms or at least by closely similar ones; and the peculiar genera *Goniophyllum* and *Petalocrinus* are known in America only from the St. Paul area of the Indiana Laurel formation and from Jones and Dubuque counties in the lower part of the Iowa Hopkinton. Unfortunately, only the echinoderms of the Laurel formation have been thoroughly studied so far, Springer listing 50 species of crinoids, 5 cystids, and 1 blastoid. Unfortunately few of these are identical specifically with species known elsewhere from other formations. (Jour. Geol., vol. 4, pp. 166–173, pls. 6, 7, *1896.*)

The Waldron fauna is developed typically in southeastern Indiana, western Kentucky, and the northern part of western Tennessee. In northeastern Indiana a closely similar fauna has been found near the middle of the Liston Creek formation at Muncie, Marion, and at Ingalls, the locality named last being 12 miles southwest of Anderson. In Ohio, a typical Waldron fauna occurs directly beneath the Euphemia dolomite at Cedarville, in Greene county. It has not been determined definitely that these additional localities are strictly contemporaneous with the typical Waldron of southern Indiana, but they at least represent invasions from the same sea.

Bassler has shown that of the 80 species of bryozoans known

from the Rochester of New York, 33 occur also in the Osgood beds of Indiana, but only 14 species in the Waldron of that state. Moreover, most of those Rochester species which occur also in the Waldron of Indiana are species of almost world-wide distribution, and may be expected from the Osgood of Indiana when the fauna of these beds becomes equally well known. When these species of world-wide distribution are discarded, only 7 Waldron species remain in common with the Rochester fauna, compared with 24 Osgood species. However, this does not alter the fact that the Waldron shows greater affinity to the Rochester than to any other Niagaran formation in New York; probably due to invasion from the same sea.

67. *Louisville limestone*

Cumings correlates the Liston Creek formation of northern Indiana with the Louisville formation of the southern half of that state and the adjacent part of Kentucky, and regards both as approximately of the same age as the Lockport of New York. Moreover, he states that the underlying Mississinewa shale of northern Indiana thins out eastward and southward so as to be absent at Lewisburg, Ohio, and at Richmond, Indiana.

At Bledsoe, in Sumner county, Tennessee, the relative stratigraphical distribution of Pentamerus cf. oblongus and of *Rhipidium knappi* and *Rhipidium nysius* suggests the Louisville age of the exposures in that area. The exposures southwest of Nashville, formerly referred to the Louisville, require further study.

Bassler has shown that 30 species of corals occurring in the upper part of the Louisville formation at Louisville, Kentucky, are known also from the upper part of the Lobelville formation in western Tennessee, thus correlating the tops of these formations in the areas mentioned. The possibility that lower horizons of the Brownsport group of western Tennessee also have Louisville affinities is suggested by the presence of three species characteristic of the Beech River formation in western Tennessee also in the Louisville formation of Kentucky. These three species are *Anisocrinus greenei*, *Macrostylocrinus meeki*, and *Troostocrinus reinwardti*. Another species showing Brownsport affinities among

the species known at Louisville is *Astraeospongia meniscus,* which in the area southeast of Charlestown, Indiana, occurs 22 feet below the top of the Louisville formation. *Melocrinus oblongus* is listed by Springer both from the Louisville formation at Louisville and also from the Bob formation in Decatur county, Tennessee, but this species is listed by Bassler also from the Laurel at St. Paul, Indiana. Judging from these very inadequate observations it is possible that the Louisville formation is equivalent not only to the Lobelville member of the Brownsport group, but also to some of its lower members, especially in view of the fact that almost nothing is known of the fauna of the middle and lower parts of the Louisville formation in its area of typical development.

68. Silurian of western Tennessee

The Lockport division of the Niagaran in western Tennessee includes the following formations, in ascending order: Laurel limestone, Waldron shale, Lego limestone, Dixon shale, Beech River formation, Bob formation, Lobelville formation, and Decatur formation. Of these, the Laurel formation is identified chiefly by lithological and stratigraphical resemblances with more typical exposures as seen farther north, in western Kentucky and southern Indiana. The Waldron fauna, on the contrary, is abundantly and typically developed at Newsom, 14 miles southwest of Nashville, and a few species characteristic of the Waldron at Swallow Bluff and Iron City can be traced northward as far as Newsom, so as to tie up with the more abundant fauna found there.

The Lego limestone is identified chiefly by its location directly over the Waldron shale and beneath the Dixon clay. On stratigraphical grounds this limestone was identified by Foerste with the lower part of the Louisville limestone of Kentucky. However, no fossils are known from the Lego limestone in its area of typical development so that this correlation with the lower part of the Louisville limestone needs confirmation.

The Dixon clay shale also is almost unfossiliferous. At its top it contains *Fistulipora hemispherica, Pisocrinus tennesseensis,* and *Pisocrinus granulosus,* the two species named first ranging upward

into the Brownsport group. Possibly this Dixon clay is to be regarded as the basal formation of the Brownsport group.

The Brownsport division of Foerste includes the Beech River, Bob, Lobelville, and Decatur formations of Pate and Bassler.

Of these, the Beech River formation is most prolific in echinoderms, Springer listing 70 species of crinoids, 3 cystids, and one blastoid from this formation. In contrast with this large number from the Beech River, Springer lists only 2 crinoids from the Bob formation, 2 species of *Pisocrinus* from the Lobelville, and 6 crinoids from the Decatur.

While the fauna of the Brownsport group is large, few species, except the crinoids, have been assigned to the formations proposed by Pate and Bassler. Those listed by these authors from the Beech River formation are: *Astraeospongia meniscus*, *Carpomanon stellatimsulcatum*, *Caryomanon incisolobatum*, *Palaeomanon cratera*, *Fenestella acuticosta*, *Fistulipora hemispherica*, *Isorthis arcuaria*, *Schizoramma fissiplica*, and *Eospirifer oligoptychus*.

The overlying Bob formation contains: *Astylospongia praemorsa*, *Carpomanon stellatimsulcatum*, *Schuchertella subplana*, *Atrypa niagarensis*, *Dictyonella gibbosa*, *Gypidula roemeri*, *Merista tennesseensis*, *Nucleospira concentrica*, *Rhipidium* sp., *Stegerhynchus neglecta*, *Uncinulus stricklandi*, *Uncinulus tennesseensis*, and *Wilsonia saffordi*. Of these, *Uncinulus stricklandi* is characteristic of the lower third of the formation, *Rhipidium* is characteristic of its upper part, while the remainder occupy the middle third. Of the crinoids, Springer listed only *Melocrinus oblongus* and *Technocrinus niagarensis* from the Bob formation.

The Lobelville formation, in addition to the 31 species of corals listed by Pate and Bassler, contains *Atrypa niagarensis*, *Meristina maria roemeri*, *Eospirifer foggi*, *Uncinulus stricklandi*, and *Wilsonia saffordi*. The only crinoids referred by Springer to the Lobelville are *Pisocrinus gorbyi* and *Pisocrinus sphericus*.

From the Decatur formation Pate and Bassler list only *Pachydictya crassa*, *Glauconome* sp., *Uncinulus stricklandi*, and *Wilsonia saffordi*. Foerste found *Astraeospongia meniscus* at the top of the formation. Springer described *Aorocrinus nodosus*, *Clono-*

crinus occidentalis, *Cremacrinus decatur*, *Eucalyptocrinus pernodosus*, *Eucalyptocrinus sculptilis*, and *Mariacrinus rotundus*. This is a Niagaran fauna in which such species as *Aorocrinus nodosus*, *Eucalyptocrinus sculptilis*, and *Mariacrinus rotundus* are distinctly aberrant from the usual type of structure found in the most nearly related Niagaran forms.

Admitting the correlation of the Lobelville formation with the top of the Louisville formation in the Louisville area of northern Kentucky and the adjacent part of Indiana, it has not been demonstrated where the base of this Louisville formation belongs in terms of the formations proposed for the Niagaran formations of western Tennessee. The possibility of securing additional information bearing on this subject both in the Louisville area and in the northern part of western Tennessee has not been exhausted.

In a general way the Brownsport group of formations appears related to the Bainbridge group of Missouri, apparently including formations as low as the Dixon clay shale, and as high as the Lobelville, judging from the species of *Pisocrinus* studied by Springer.

69. Cayugan of western Ohio

In the area here under consideration the Cayugan is represented, in ascending order, by the Greenfield, Tymochtee, Put-in-Bay, and Raisin River dolomites of western Ohio. In this sequence, the Tymochtee fauna is practically a continuation of the Greenfield fauna, some of the forms being depauperate. Cumings and Shrock regard this Greenfield-Tymochtee succession as equivalent to the Kokomo limestone of northern Indiana and the Bertie waterlime of New York and Canada.

Bassler identifies the *Eurypterus eriensis* of the Put-in-Bay dolomite with the *Eurypterus microphthalmus* of the Manlius of New York. This suggests the correlation of the two formations named. The Raisin River formation may be merely a later member of the Manlius sequence as exposed in northwestern Ohio.

O. DIRECTION OF ORIGIN OF SILURIAN FAUNAS

70. Eastern and southern sources

The Silurian formations here under discussion represent shallow water deposits made on the floor of epicontinental seas. Assuming that the general distribution of continental and oceanic sectors in Paleozoic times was somewhat similar to that existing at present, attempts have been made to determine the approximate source of the different faunas involved. The evidence consists chiefly in the present known geographical distribution of the different Silurian faunas. It is assumed that recurrent invasions from the same sea would result in similar faunas, though differing sufficiently in successive formations to show varietal and specific changes. On the other hand, more fundamental differences might be expected between faunas derived from different seas.

Based on this line of reasoning, only the Ribolt, Bisher, and Cayugan faunas suggest derivation from an eastern or Atlantic source. All the remaining Silurian faunas of Ohio, Indiana, Kentucky, Tennessee, and Alabama apparently entered from the south.

The southern avenue of approach need not be considered as a relatively narrow channel, but may have been very wide, with little regard to present structural features.

Thus, the Oldham fauna, and possibly also the Dayton fauna, has affinities with the Lower Clinton fauna of the Birmingham area of Alabama. This is true also of the fauna associated with the large crinoid beads at the top of the Brassfield formation east of the Cincinnati anticline in Ohio, and eastern Kentucky. In fact, most of the Silurian faunas east of the Cincinnati anticline during Niagaran times show considerable difference from those faunas found west of this anticline. This is true especially of the Euphemia, Springfield, and Cedarville faunas, and of the overlying Cayugan faunas. So little is known of the Osgood and Laurel faunas as identified in Ohio that these faunas do not enter into the problem. A small Waldron faunule makes its appearance at Cedarville, Ohio. In general, however, all of the Silurian faunas east of the Cincinnati anticline, except the Brassfield,

appear to have had an origin sufficiently distinct from that west of this anticline to make the resulting faunas conspicuously different.

The Brassfield, Osgood, and Waldron faunas apparently represent recurrent invasions of the same sea. Although the Brassfield fauna is developed best on the eastern side of the Cincinnati anticline, the typical Osgood and Waldron faunas are found west of this anticline, with the exception of the small incursion of Waldron in the Cedarville area already mentioned.

The typical Laurel fauna appears to be an early incursion of that fauna which later produced the Louisville invasion. It is certain that the upper parts of the Louisville and Brownsport faunas are related.

Possibly the Cincinnati anticline originally extended considerably farther south than the most southern part exposed at present, at least during Niagaran times. It is possible that a distinct increase in elevation of this arch took place in post-Brassfield times, sufficient to account for the faunal differences noted east and west of its crest.

Moreover, the crest of this anticline in Silurian times may have had a location different from that known at present. During Brassfield times it may have been as far west as western Ripley and eastern Jennings counties in Indiana. During Osgood and Laurel times it may have been nearer western Ohio. The Waldron shale, a clastic deposit, may have been deposited on the flanks of this anticline, and not on its crest.

It is evident that most of these conclusions are only tentative. It is possible that strata containing very dissimilar faunas may be essentially synchronous in age. This is true especially of strata whose faunas invaded from different oceanic basins. Obviously, faunal differences may arise also from differences in biologic conditions prevailing in neighboring epicontinental basins, such as differences in depth, temperature, salinity, direction of currents, bottom conditions, and so forth. However, the extent to which these data affect differences in faunal segregations on the continental shelves of modern seas has not been studied sufficiently as yet to be applied with confidence to Paleozoic seas.

P. AGE OF CINCINNATI AND NASHVILLE ANTICLINE

The initial stages of the Cincinnati dome may have risen above sea level already in Richmond, and possibly even in preceding Cincinnatian times. In Brassfield times it is evident that the sea transgressed the crest of the dome on its northern side at least as far south as the northern margins of Butler and Warren counties in Ohio. In central Kentucky it probably crossed the dome in Boyle and Marion counties. Whether the central part of the dome rose above sea level during Brassfield times can not be determined with confidence but the possibility of such a rise cannot be denied.

The rise of the Nashville dome in central Tennessee in pre-Silurian times may be assumed more readily, the Brassfield formation being absent on its southwestern flanks locally, and probably being absent over greater areas in that state on approaching the crest of this more southern dome.

In Clinton and Niagaran times, however, the separation of the seas on the eastern and western sides of the Cincinnati anticline seems to have been sufficient to give rise to very dissimilar faunas on the two sides the crest of the arch uniting these two domes.

In Clinton times, for instance, none of the Clinton faunas known on the eastern side of the Cincinnati anticline, the Oldham, Waco, Dayton, Ribolt, and Bisher, occur on its western side, where the only known Clinton fauna is the Osgood, which differs conspicuously from that of Bisher which is its nearest contemporary on the eastern side of the anticline.

This is true, though to a less degree, also during Lockport times. Although the Laurel formation, on stratigraphical and lithological grounds, is traced across the crest of the anticline into Preble, Miami, and Greene counties, Ohio, the characteristic Laurel fauna of Indiana has not been found in that state. The typical Waldron fauna of central Indiana is known in Ohio only at Cedarville. No equivalents of the Lego, Dixon, or Brownsport faunas are known east of the anticline. It is doubtful whether any part of the Lilley fauna of Highland county, Ohio, can be identified as identical with that of the Louisville in Kentucky. In a similar

manner, the members of the Durbin group, the Euphemia, Springfield, and Cedarville dolomites of southwestern Ohio, can be traced only a short distance west of the western boundary of Ohio, Cumings having found a similar lithological sequence at Ridgeville, about 10 miles west of the Ohio boundary, in the northern part of Randolph county, Indiana, 25 miles northwest of Greenville, Ohio. To what extent the typical Durbin faunas of Ohio can be identified in the Ridgeville area has not yet been determined, but the known Lockport faunas of the more western exposures in northern Indiana are known to be quite different.

In a similar manner, the Peebles fauna of southern Ohio differs considerably from the Huntingdon fauna of northern Indiana, though both are approximately of Guelph age, and both probably were connected through northern Ohio and Indiana.

Finally, the Bass Island group of western Ohio and adjacent Michigan, including the Greenfield, Tymochtee, Put-in-Bay and Raisin River dolomites, contain a fauna differing from that of the Kokomo and Kenneth limestones of northern Indiana.

From this it is assumed not that the seas east and west of the Cincinnati anticline were completely isolated, but that they were sufficiently obstructed to permit the development of distinct series of faunas.

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INDEX TO SILURIAN FAUNAS

In the following index to lists of fossils from various Silurian formations in the area here under consideration, the first number refers to the publication bearing the same number in the preceding Bibliography. The second number is the page reference. For convenience the names of formations are given in alphebetical order.

A STUDY OF THE PHENOMENON OF WETTING FILMS

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The wetting method of measuring the depth of a liquid in a container is extremely inaccurate; this is especially true in the case of gasoline, naphtha and alcohol. In attempting to solve the problem of measuring accurately the depth of gasoline in an underground tank, a problem which is developing serious labor difficulties and enormous economic loss, a very curious phenomenon was observed. Gasoline was found to wet a vertical glass plate to a height much greater than could be accounted for by the phenomenon of capillarity.

This phenomenon has been termed the "wetting film," to distinguish it from the "wringing film" and the "adsorbed film."

Wringing Film. Rolt (*1*) in speaking of the "Wringing" of Block Gauges says,

> A most valuable feature of these gauges is the fact that it is possible to "wring" two or more gauges together, by first cleaning them and then bringing their faces into contact with a combined sliding and twisting motion. . . . . The adherence is due almost entirely to the presence of a liquid film between the faces. . . . . It is interesting to note that this minimum thickness found for wringing films is roughly twice the accepted value of the radius of molecular attraction—a relationship which offers explanations for most of the properties associated with the phenomenon of wringing.

The radius of molecular attraction was measured by Chamberlain (*2*) in 1910.

Quincke (*3*), in 1869, made an attempt to measure the radius of molecular attraction, hereafter designated as R, and concluded that it was greater than 5×10^{-6} cm. It was generally agreed that a liquid film could not exist less than $3R$ thick. Reinhold

and Rucker, in 1881 (*4*), 1883 (*5*), and 1893 (*6*) measured liquid films 1.2×10^{-6} cm. thick. Johonott and Chamberlain (*7*), in 1899, measured films 0.6×10^{-6} cm. thick, and observed the splitting of the Reinhold and Rucker film, and the reverse phenomenon of doubling. These results made it impossible to longer accept Quincke's determination of R.

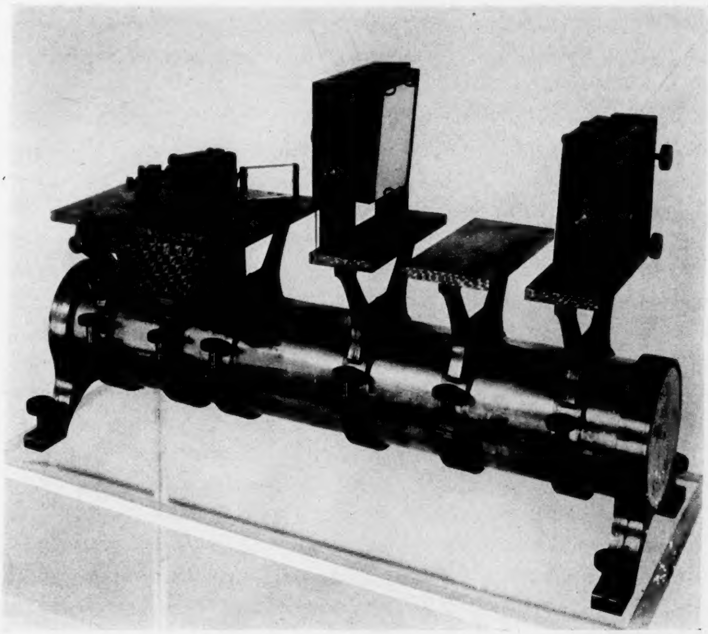

FIG. 1. COMPOUND INTERFEROMETER

As the value of R is far beyond the limit of the best compound microscope it was necessary to employ a new type of measuring instrument. Chamberlain designed the Compound Interferometer at Denison University and with the assistance of Ernst Keil, instrument maker of the Department of Physics in Barney Science Laboratory, constructed the instrument shown above (Fig. 1).

The optical parts, possessing an accuracy greater than one twentieth of light wave, were figured by O. L. Petitdidier. The value of R was found to be 1.5×10^{-7} cm. or one and one-half millionths of a millimeter. Films one R thick are twenty times smaller than can be observed by the best compound microscope and, in the case of water, such a film is approximately five molecules thick.

Adsorbed Film. An absorbed film is a layer of a liquid or gas which has condensed on a solid surface. It is a manifestation of the force of adhesion.

Wetting Film. A wetting film is that film which spreads over a solid or liquid surface making contact at an angle with the liquid surface.

Liquids which Produce Wetting Films. While the present investigation was undertaken to determine the cause of the large wetting film of gasoline, and the varying character of this film, many liquids were examined to determine which ones possess the ability to form wetting films, and possibly to throw light upon the cause of the phenomenon.

Ethyl alcohol (C_2H_5OH) has a wetting film which creeps very rapidly up the surfaces of silver and glass. Measurements on alcohol were not taken for two reasons: first, because of the work of Langmuir and second, because it seemed advisable to confine the experimental procedure to hydrocarbons. Results of this investigation show why alcohol creeps up the sides of a glass container. Langmuir (*8*) gives an explanation of the spreading of organic molecules, having the $-COOH$, $-CO$, and $-OH$ radicals, over liquid surfaces. While it is true that alcohol creeps up a vertical glass plate, the glass plate must have on it a wringing film, as has been shown by Chamberlain.

Ether was found to creep, producing a very thin wetting film.

Gasoline forms a wetting film in rather a violent manner. It was impossible to account for the wetting film by capillarity. In general new films can be produced by two methods: (1) disturbing the surface, producing a small wavelet; (2) by introducing a small amount of air near the surface of the gasoline. Different samples

of gasoline were tried, as well as treated and untreated gasoline, and in each case a wetting film was formed.

A sample of ordinary cleaning naphtha was found to produce a wetting film, but not so great as that of gasoline.

Turpentine, which has as its main constituent pinene, was found to act very much like naphtha, producing an appreciable wetting film.

Liquids which Produce no Wetting Films. Acetone and benzene form no wetting films.

Castor oil, $(C_{17}H_{32}(OH)COO)_3C_3H_5$, does not creep up the sides of a vertical container, but it does spread over the surface of water according to Langmuir's theory, if placed on the water in small quantities.

Distillate, a product formed during the distillation of crude oil, does not creep.

Fuel oil grade "A," which contains hydrocarbons of high molecular weight, was found not to creep.

Treated and untreated kerosenes do not produce wetting films. By a treated kerosene or gasoline is meant one which has been treated with sodium plumbite (Na_2PbO_2) to remove the sulfur.

The fact that kerosene does not creep is contrary to statements made by many authors. This can be explained by the conclusions reached in this investigation. The old kerosene, because of the commercial demand, was distilled between a wide range of temperature. The demand for modern gasolines has increased to such an extent that the range over which gasoline is distilled is increased, thus making it necessary to decrease the limits for the distillation of kerosene.

Hydrogen peroxide and dilute acetic acid (CH_3COOH) do not creep.

Xylene gave results which were very similar to benzene, showing no wetting film.

Cenco pump oil, paraffin oil and a medium grade of motor oil were found to produce no wetting film.

Wetting Films from Mixtures of Liquids not Producing Wetting Films. In mixing different liquids, in an attempt to stop the formation of the wetting film and also to see if the effect could be

increased, a very interesting phenomenon was observed. It was found that certain hydrocarbons which in themselves would not produce a wetting film did have a wetting film when mixed. In Table I are the percentages of liquids used when the first observable wetting film was noted.

In connection with the mixing of benzene and xylene with ether it must be remembered that it was previously stated that ether had a very thin wetting film.

The wetting film in some of the above cases is slight, but it was found that if the proportion of xylene or benzene was increased

TABLE I

Percentage by volume

Cenco pump oil	50	Xylene	50
Paraffin oil	33.3	Xylene	66.7
Fuel oil Grade "A"	50	Xylene	50
Kerosene	50	Xylene	50
Xylene	50	Benzene	50
Cenco Pump oil	50	Benzene	50
Paraffin oil	33.3	Benzene	66.7
Fuel oil Grade "A"	50	Benzene	50
Kerosene	50	Benzene	50
Benzene	50	Ether	50
Xylene	50	Ether	50

Paraffin oil 12.5, Cenco pump oil 12.5, Ether 12.5, and Benzene 62.5.

the rapidity with which it rises increases as the amounts of xylene and benzene are increased.

It should also be noted that all mixtures containing benzene and xylene contain equal amounts of each component.

Saturated and Unsaturated Hydrocarbons. The cracking process produces unsaturated hydrocarbons in the gasoline. To investigate their effect in producing the wetting film the unsaturated hydrocarbons were removed. This was done by two methods, *viz:*

(1) 50 cc. of concentrated sulfuric acid were mixed with 500 cc. of gasoline and the resulting mixture placed in a mechanical shaker for 2.5 hours. The mixture was then placed in a separatory funnel and the unsaturated gasoline and carbon compounds were poured out the bottom of the funnel. To the remaining gasoline

another 50 cc. of concentrated sulfuric acid was added and the mixture again placed in the mechanical shaker for two hours. Again the unsaturated gasoline and carbon compounds were separated out by the separatory funnel.

With a small sample of gasoline the bromine test for unsaturated hydrocarbons was made. The testing liquid was a solution of water saturated with bromine. The disappearance of the bromine color indicated that all of the unsaturated hydrocarbons had not been removed by the sulfuric acid. It was now necessary to add another 50 cc. of concentrated sulfuric acid to the gasoline and shake as before until the gasoline was completely free from unsaturated hydrocarbons. To this (saturated) gasoline a 10 per

TABLE II

Treated gasoline	Wetting film	Saturated
Treated kerosene	No wetting film	Saturated
Untreated gasoline	Wetting film	Saturated
Untreated kerosene	No wetting film	Saturated in itself but unsaturated due to sulfur content
Untreated distillate	No wetting film	Unsaturated
Treated fuel oil, Grade "A"	No wetting film	Unsaturated
Naphtha	Wetting film	Unsaturated
Alpha-phenyl-beta-pentene	No wetting film	Unsaturated

cent solution of sodium carbonate (Na_2CO_3) was added, the mixture was placed in the mechanical shaker for fifteen minutes, and the precipitate thus formed was drained off. The resulting gasoline solution was washed twice and the water drained off through the separatory funnel. Anhydrous calcium chloride ($CaCl_2$) was added to the gasoline and allowed to stand over night to remove the water. The saturated gasoline was then poured off, and found to still produce a wetting film.

(2) Another method used to remove unsaturated hydrocarbons from gasoline was to mix with the gasoline an equal volume of a 5 per cent solution of sodium carbonate (Na_2CO_3). To this was added a 2 to 5 per cent solution of potassium permanganate ($KMnO_4$). This mixture was agitated by a mechanical shaker

until the purple color changed to brown. This operation was repeated until there was no further change in color. Distilled water was then added and the gasoline thoroughly washed, after which the water was drawn off by a separatory funnel. The remaining water was removed by anhydrous calcium chloride which was allowed to stand in the gasoline over night.

The liquids given in Table II were tested for unsaturation of the hydrocarbons, using the bromine test.

The main component of turpentine is pinene, which is unsaturated due to bending and double bond and the strain of bending is only partly neutralized by the double bond. It was found that turpentine has a wetting film. The structural formula for pinene is given in Fig. 1 Plate XXIII.

Benzene on the other hand is unsaturated due to bending and double bond, one effect just neutralizing the other. Benzene is therefore a very stable saturated compound. It was found in this investigation that benzene does not have a wetting film. Fig. 2 Plate XXIII shows the benzene structural formula.

Xylene like benzene is a perfectly saturated compound. It is unsaturated due to bending and double bond. These two effects exactly neutralize each other forming a very stable saturated compound. There are three kinds of xylene, ortho-, meta-, and para-, each having a formula $C_6H_4(CH_3)_2$ but a different structural formula, Fig. 3 Plate XXIII. In all probability the xylene used in this investigation was a mixture of the three different xylenes.

The compound alpha-phenyl-beta-pentene is unsaturated and has the structural formula shown in Fig. 4 Plate XXIII. Alpha-phenyl-beta-pentene was found to have no wetting film.

From the above results it can be seen that the creeping or wetting film in the case of mixtures of hydrocarbons does not depend upon the saturated or unsaturated condition of the hydrocarbons.

Low Temperature Combustion. Low temperature combustion was investigated as another possible source of the energy required to produce wetting films.

A jet of oxygen was passed into the vapor above liquid gasoline. It was found that the gasoline wetting film established a point of

equilibrium about 2.5 cm. above the surface of the gasoline in the container. After equilibrium was established gasoline tears rolled down the wetting film. These tears did not readily pass into the surface of the gasoline but seemed to have a tendency to return up the wetting film. If the oxygen is turned off more tears will be formed. If oxygen is again admitted just as a tear gets near the gasoline surface, it was found that the tear did not enter the surface, but entered a new wetting film which has been formed by the admission of oxygen. This new wetting film crept up the surface of the old wetting film.

Workers in the field of low temperature combustion have concluded that all surfaces apparently have the power to produce the effects of confined, flameless combustion when at high temperatures. Large surfaces will ignite inflammable gas mixtures at a lower temperature than small ones.

It is known that ionization does not play a primary rôle in flame propagation and that it is manifest rather as a result than a cause. Ionization is one of the later steps of combustion.

Many tests were made to determine if low temperature combustion was a factor in the production of wetting films. A "type K," Leeds and Northrup potentiometer was used in conjunction with thermo junctions of copper and constantan. One junction was placed in the liquid gasoline while the other was so arranged that it could be placed anywhere inside the container, either in the wetting film or in the gasoline vapor. Another set of junctions was arranged in such a way that the difference in temperature between the atmosphere and the liquid gasoline could be determined. The liquid gasoline was used as the reference temperature. The container, with its thermo junctions and liquid gasoline, was placed in a constant temperature bath.

After equilibrium was established, with the exploring thermo junction five centimeters above the liquid gasoline, a small amount of air was admitted. It was found that the gasoline vapor was slightly heated. Upon admitting more air the exploring junction was cooled but quickly reëstablished the condition of equilibrium. Measurements indicated that the gasoline vapor was slightly warmer than the liquid gasoline.

With the exploring thermo junction placed in the wetting film one centimeter above the liquid, it was found upon admitting air near the top of the container that the junction in the wetting film was cooled. A similar result was obtained when the exploring junction was placed in the wetting film two centimeters above the surface of the gasoline.

When oxygen is admitted to a tube containing gasoline a succession of wetting films rapidly followed one another notwithstanding the fact that the amount of disturbance transmitted to the surface is very small. Illuminating gas produced more rapid formation of wetting films than oxygen. The admission of air causes a wetting film to rise rapidly up the sides of a glass container.

Early Observers of Wetting Films. James Thomson (*9*), in 1855, explained "the curious motions commonly observed in the film of wine adhering to the inside of a wine-glass, when the glass, having been partially filled with wine, has been shaken so as to wet the inside above the general level of the surface of the liquid," by the "consideration that the thin film adhering to the inside of the glass must very quickly become more watery than the rest, on account of the evaporation of the alcohol contained in it being more rapid than the evaporation of the water, ... the watery portions having more tension than those which are more alcoholic, drag the latter briskly away."

Maxwell (*10*) accepted James Thomson's explanation and called attention to the reference to the phenomenon in Proverbs xxiii, 31.

Hall (*11*), while trying to prove that the angle of contact of alcohol was zero, which was doubted by many observers at that time, proposed to check the angle of contact. "If there is a finite contact-angle for each plate, the values found for T cos O will be different. If these values are all alike, it is reasonably certain that the contact-angle is zero." Hall then gives the results in tabular form. He used plates of platinum, zinc, silver, tin, glass. To compensate for the observed discrepancy in zinc and silver, Hall says,

The zinc plate was slightly wedged shaped and not very regular on the edge. There was no such irregularity in the silver plate; but on watching closely I could see that the alcohol crept rapidly up the plate, wetting it to a height of several millimeters above the normal line of contact. Several other trials with a silver plate showed the same peculiarity. There may have been something similar happening on the zinc plate, but if so I failed to detect it.

Thomson and Maxwell assumed the solid walls to have been wet by mechanical shaking and did not observe a wetting film creeping up a dry surface. Hall apparently observed an alcohol film wetting a silver surface, and believed it accounted for variations in his determinations of the angle of contact of alcohol with silver and zinc, although he observed no wetting film on the surface of zinc, mica, platinum, or glass. The single instance of spreading observed by Hall can be explained on Langmuir's theory, as alcohol contains an hydroxyl (OH) radical. It thus appears that true wetting films have not been given previous study.

Surface Tension. The relationship between wetting films and surface tension was next investigated. According to Laplace's theory of surface tension (*13*) the contractile force of liquid surfaces is attributed to the attractions of the molecules immediately below the surface of the liquid for those on the surface, producing a tendency for the surface molecules to move into the interior. Foley (*13*) has offered the following objections to Laplace's theory. The magnitude of the force normal to the surface would depend on the curvature of the surface and would be greater at a convex surface than at a flat or concave surface. Consequently the rise of water in a capillary tube would be due to the fact that the downward pressure of the film outside the tube is greater than the downward pressure of the film inside the tube. Two simple experiments show the fallacy of Laplace's theory.

Suppose a long capillary tube be taken and its lower end placed some distance into the water and the height of the capillary column noted. Now drop some soap solution on the water *outside* the tube and thus lower the tension outside. If the liquid is supported by the excess of pressure outside the tube, the height

of the capillary column should be lessened. On the contrary the height remains constant for some time.

If the experiment be repeated but this time placing the soap solution *inside* the capillary tube, the tension inside the tube is reduced (demanding a reduced pressure inside) and the outer pressure remaining constant, it would seem according to Laplace that the excess of the outside pressure would be increased and that the water should rise in the capillary. Instead of rising it immediately falls.

TABLE III

TEMPERATURE	SURFACE TENSION		
	Naphtha	Turpentine	Gasoline
°C.	*dynes/cm.*	*dynes/cm.*	*dynes/cm.*
43			24.08
40		29.24	24.22
38		29.24	24.63
36			24.91
35		29.72	
34		29.86	25.04
32	25.11	29.93	25.18
30	25.18	30.27	25.32
28	25.46	30.62	25.46
26	25.73	30.82	25.46
24.5		30.89	
24	25.80		25.87
23	26.01		

Randall, Williams, and Colby (*14*) give a very acceptable explanation of surface tension. Suppose in a container the molecules in the surface are considered. They will have an attraction for any molecule situated within the radius of molecular attraction. Likewise molecules within this distance from the walls of the container will exert a force of attraction for the walls. Suppose now that a molecule is slipped out of the surface layer by some means or other. When this happens the surface at that instant is slightly smaller then it was previously. This diminution of the area of the free surface causes the phenomenon known as surface tension. This dynamic explanation of surface tension constitutes a more useful conception of the phenomenon.

The surface tensions of naphtha, turpentine, and gasoline were measured with a platinum ring on a torsion du Noüy tensiometer. The values of the surface tensions are given in Table III.

Effect of Saturated Vapor above Gasoline Surfaces. If a container partly filled with gasoline and sealed is allowed to stand, the space above the gasoline becomes saturated with gasoline vapor providing some liquid gasoline remains in the container. When this condition of saturation is reached it is impossible to start a wetting film by means of a wavelet on the liquid surface.

Measurements of Pseudo Viscosity. Measurements of the pseudo viscosity were taken for gasoline, naphtha, and turpentine. The measurements were taken with a Tag-Saybolt Universal Thermostatic Viscosimeter. In this type of instrument the time

TABLE IV

TEMPERATURE	TIME OF FLOW		
	Naphtha	Turpentine	Gasoline
°C.	*seconds*	*seconds*	*seconds*
5			29.2
10	30.0	35.6	
20	30.0	36.0	29.4
30	30.0	34.1	29.6
40	33.1	33.0	30.0

in seconds is determined for the flow of a definite amount (60 cc.) of the material at the required temperature through a given opening. The temperatures and times of flow are given in Table IV.

The pseudo viscosity measurements include all factors affecting resistance to shear as well as the true viscosity of the liquids; the latter would increase, while the former would, in general, decrease with increased temperature. Table IV indicates a negligible change of pseudo viscosity with change of temperature in the case of the three liquids examined, and that wetting films are not caused by the small changes in temperature due to surface combustion.

Method of Measurement. The source of the energy required to produce wetting films was found by means of the universal inter-

ferometer used in the measurement of the radius of molecular attraction. It was designed and constructed in the Barney Science Laboratory at Denison University. Plate XXIV shows a plan of the instrument. A beam of light from a mercury arc, made monochromatic by the use of filters, is incident upon a plate silvered with a 50 per cent film on the side toward the source. In order to utilize the largest possible aperture the beam must have an angle of incidence of 45 degrees. At the 50 per cent film the beam is divided into transmitted and reflected portions each meeting an end mirror (3 and 4) adjusted so as to reflect the light beams parallel to each other and to the dividing plate. Plate XXIV shows the angles which the end mirrors make with the axis of the instrument. The beam transmitted by the plane parallel dividing plate is parallel to the incident beam and is reflected by the end mirror (3) in a direction parallel to the dividing plate and the axis of the interferometer. The angle $2x$, therefore, equals 45°. The angle between the end mirror and the axis of the instrument, or the dividing plate, is $90°-x$ or 67.5°. The transmitted and reflected rays are reflected by the end mirrors to a large mirror m_1. If they meet this mirror at perpendicular incidence they are returned upon themselves to the dividing film where they undergo a second division. The reflected portion of the transmitted ray and the transmitted portion of the reflected ray are received in the telescope of a cathetometer, and Fizeau interference fringes observed in the plane of the mirror m_1. If the instrument is to be used as a compound interferometer the mirror m_1 is tilted so that the beam is reflected to the mirror m_2 which is elevated just enough to allow the beam coming from the end mirrors to pass under to mirror m_1. The angle between the mirrors m_1 and m_2 can be adjusted so as to produce any desired number of reflections between them, the interfering beams eventually meeting one of the mirrors at perpendicular incidence and returning upon themselves, producing interference bands of any desired order.

The wetting film to be measured was placed on an optical plate placed between m_1 and m_2 in such a way that clear glass was in one of the two interfering paths and glass with the wetting film was in the other. The glass plate extended through both paths so that no correction for the increased optical path was necessary.

The bed plates carrying the dividing mirror, end mirrors, compensating plate, the mirror m_2, and the mirror m_1, are clamped on a large bronze tube. They can therefore be moved to any desirable position on the tube. The end mirror (4) is fastened directly to the bed plate in such a way that it can be rotated about its center. The mirror (3) can also be rotated about its center and is connected through an opening in the bed plate to the movable carriage of a small but exceedingly accurate interferometer. This makes it possible to move mirror (3) forward and backward and in this way lengthen or shorten the optical path of this beam.

Because of the difficulty in producing a collimated beam of light, the adjustment of the mirrors can best be made using a beam of sunlight. The successive images are seen on the mirrors m_1 and m_2, and the order of the compounding, can easily be determined.

The optical plate upon which the wetting film was allowed to creep was divided into two parts by a strip of collodion. On the bottom of half of this plate was fitted a container coated with collodion.

The material under observation was placed in the container and the wetting film formed on half of the optical plate. This placed the wetting film in one optical path of the interferometer and at the same time provided a means of placing the same thickness of optical glass in both paths.

The formula used in calculating the thickness of the wetting film is $D = \frac{\delta\lambda}{N(n'-1)}$, where D is the thickness of the wetting film, δ the interference fringe displacement in terms of number of fringes, λ the wave length of light employed, N the number of times the light passes through the wetting film, and n' the index of refraction of the wetting liquid. The total change in optical path is $\delta\lambda$, $\delta\lambda/N$ the change in optical path due to one interfering ray passing once through the wetting film, and $(n' - 1)$ the difference between the index of refraction of the wetting film and the index of refraction of air which the wetting film displaces.

The fringe displacement was measured with a cathetometer

fitted with a micrometer eyepiece. In every case many readings were taken and the average of the readings used in the calculations.

The index of refraction of the materials was measured with an Abbé refractometer, and here again the value taken was the average of many readings. Table V shows the indices of refraction of several liquids as measured by the Abbé refractometer, the temperature in each case being 22° centigrade.

TABLE V

Saturated Gasoline	1.4209
Unsaturated Gasoline	1.4302 to 1.4279
Naphtha	1.4191
Turpentine	1.4720
Benzene	1.4980
Xylene	1.4953
Ethyl Alcohol	1.3629
Acetone	1.3590

TABLE VI

GROUP 1		GROUP 2		GROUP 3	
Temperature	Thickness of wetting film	Temperature	Thickness of wetting film	Temperature	Thickness of wetting film
°C.	cm.	°C.	cm.	°C.	cm.
23.5	0.0000311	18.0	0.0000335	16.0	0.0000427
24.0	0.0000356	19.0	0.0000392	18.0	0.0000478
		20.0	0.0000443	19.0	0.0000494
		21.0	0.0000479	25.0	0.0000536

Thickness of Wetting Films. The thickness of the wetting films of naphtha are given in Table VI. The three groups of results are for the same naphtha, but the values represent longer exposure to the atmosphere. The naphtha in group 2 had been exposed longer than the naphtha in group 1. Likewise the naphtha in group 3 had been exposed longer than the naphtha of group 2.

In making the above measurements the green line of the mercury arc 0.0000546073 cm. was used. The values of n′, the index of refraction of the various materials used, are given in Table V.

Table VI shows that the longer a given liquid is exposed to the

atmosphere the thicker becomes the wetting film for any given temperature. There is also an increase in the thickness of the wetting film resulting from an increase in temperature.

The diagram, Fig. 1 Plate XXV, shows a typical wetting film of naphtha. In the center of the diagram can be seen interference patterns which are irregular in nature. This is due to the débris which has been carried to the top of the wetting film and left there when the film drains, and also to tears which are formed at the top of the film. The narrow interference bands in this region show that the tears and débris are approximately ten times the thickness of the wetting films, which is determined by measuring the displacement of the Fizeau bands in the upper and lower portions of Fig. 1.

TABLE VII

TEMPERATURE DIFFERENCE	DIFFERENCE IN THICKNESS OF FILMS	DIFFERENCE IN THICKNESS OF FILM PER DEGREE CHANGE IN TEMPERATURE
°C.	cm.	cm.
1	0.0000057	0.0000057
1	0.0000051	0.0000051
1	0.0000036	0.0000036
2	0.0000108	0.0000054
2	0.0000087	0.00000435
3	0.0000144	0.0000048

Upon observing the wetting films with a telescope they were seen to split at the top one or more times. It was also observed that new wetting films creep up over the old wetting films and these new films were extremely flat across the top and had a very sharp radius of curvature at the upper edge. This suggested that wetting films vary in thickness by some constant. This was found to be the case. Taking the values for the thicknesses of the wetting films with their corresponding temperatures from group 2 of Table VI and obtaining all of the possible combinations by subtracting the various thickness from each other, one obtains the thicknesses of film which correspond to the different degrees of temperature, as shown in Table VII.

If the differences in thickness of film per degree change in tem-

perature are now divided by the radius of molecular attraction, 1.5×10^{-7} cm. it is found that they are exactly multiples of this value. The results are accordingly 38.00R, 34.00R, 24.00R, 36.00R, 29.00R, and 32.00R. It appears from this calculation that the wetting films split along planes of cleavage one R apart. Successive wetting films differ in thickness by R or multiples of R.

Flow of Liquid in Wetting Films. Wetting films have been observed 10 cm. above the liquid surface; the height depending on the solid surface, the nature, age, and temperature of the liquid, and the degree of saturation of the vapor space. A study of the phenomena illustrated in Fig. 1 Plate XXVI showed the presence of vigorous motions in the wetting film. While under fixed conditions wetting films always rose to an equilibrium point there were many indications that this equilibrium was a dynamic one. Observations with interferometer showed the formation of successive wetting films creeping up over the preceding film. The motion which was continuous as long as the vapor space was unsaturated, could be explained on the assumption that the liquid adjacent to the solid was descending while the outer portion was ascending. Attempts were made to observe the oppositely moving currents by means of suspended particles. As the thickest wetting films measured were only one wave length thick it is readily seem that a particle small enough to be suspended in the downward flowing liquid, contacting neither the solid wall nor the upward flowing liquid, would be beyond the limit of resolution of the best compound microscope. The continuous upward movements were readily observed, but the particles were caught by the solid wall when the liquid current turned downward.

The predicted phenomena were readily observed, however, when a creeping liquid, containing small suspended particles, was introduced into a receiver, the bottom of which was concave upward. The plano-convex drop of liquid thus formed was surrounded by a wetting film. The microscope plainly showed the suspended particles rising in the center of the drop, flowing outward in the upper portions and toward the center in the lower portions of the drop. The vigorous motions were maintained as long as evaporation continued.

The Effect of Age and Temperature on the Surface Tension of Naphtha. Table VIII shows the effect of temperature on surface tension for fresh naphtha and for stale naphtha; that is naphtha which was exposed to the atmosphere in order that the more volatile fractions might evaporate.

The curves representing these values are given in Fig. 2 Plate XXV.

Evaporation at Curved Surfaces. Surface tension, according to Ewing (*15*), is the skin of a liquid at any surface which separates liquid from vapor and is the seat of a definite amount of potential energy. One of the results of surface tension is to make the conditions of equilibrium between liquid and vapor depend upon the curvature of the liquid surface. The normal conditions for equilibrium between vapor and liquid apply only to flat surfaces. In this condition the vapor, at the same temperature as the liquid, has what is called a saturated vapor pressure for that temperature. In consequence of surface tension a small drop will evaporate into an atmosphere that would be saturated or even supersaturated with respect to large drops or large quantities of the liquid, because the vapor pressure which is required to prevent evaporation from the curved surface of a small drop is greater than the vapor pressure which will prevent evaporation from a flat surface of the same liquid at the same temperature. The equilibrium vapor

TABLE VIII

TEMPERATURE	SURFACE TENSION	
	Fresh naphtha	Stale naphtha
°C.	*dynes/cm.*	*dynes/cm.*
37.0		26.49
35.0		26.49
32.0	25.11	26.69
30.0	25.18	26.98
28.0	25.46	27.19
26.0	25.73	27.59
24.0	25.80	27.66
23.0	26.01	28.21
22.5		28.44

pressure for a small drop is higher than the normal saturation pressure.

Again as the result of surface tension, the energy contained in a drop of liquid is greater than the energy contained in an equal volume of liquid when it forms a part of a mass of the same liquid at the same temperature. Due to surface tension, a small drop contains more energy per unit mass than a large drop of the same liquid at the same temperature, because the small drop has a relatively larger area. The area of the surface layer can be taken as a measure of the stored energy.

When the thickness of a vertical liquid film is reduced to eight times the radius of molecular attraction its surfaces are parallel. If such films are stretched, or allowed to evaporate, they split in the middle, and exist in stable form 4 R thick. Such films, known as the first and second black, because of their low reflection power, are too thin to produce distinctive interference between the light rays reflected from the front and back surfaces. Films of greater thickness than the first black show Newton's interference bands in colors but they store the same potential energy in their surfaces.

If a drop is evaporating under conditions which keep its temperature constant, energy must be supplied in proportion to its loss of mass to provide for its latent heat of vaporization. The drop will lose some of its surface energy because it is decreasing in size, and this supplies part of the latent heat, the remainder coming from the outside. A drop will evaporate into a space which is saturated for the same liquid in large quantities. Thus it is seen that there can be no equilibrium between a drop and a surrounding atmosphere of saturated vapor. As the drop gets smaller a point is reached in which the loss of potential energy due to the contraction of the surface supplies all the latent heat of vaporization. After this point is reached the drop will continue to evaporate without any outside supply of heat.

The equilibrium between a liquid and vapor depends upon the curvature of the surface between them, if they are at the same temperature. Liquid with a flat surface is in equilibrium with the vapor above it when the vapor is at the pressure of saturation and there is no tendency on the whole for the liquid to evaporate or the vapor to condense.

A liquid having a convex curved surface is in equilibrium with the vapor only when the vapor pressure exceeds the normal saturation pressure by a definite amount, that is, only when the vapor is sufficiently supersaturated.

The degree of supersaturation necessary for equilibrium depends upon the curvature of the surface, in a manner first established by Kelvin (*16*). Kelvin's formula is $\log_e \frac{p'}{p_s} = \frac{2S}{RT\rho r}$ where P' is the equilibrium vapor pressure over a curved surface and P_s is normal pressure of saturation, and S is the surface tension in dynes per linear centimeter. By assuming a perfect gas, RT was put equal to PV. The value of RT is for a gram molecule, and must be divided by the molecular weight of the liquid to reduce the value to cgs units, ρ is the density of the liquid and r the radius of a drop of liquid assumed to the spherical. This formula determines the pressure P' which must be maintained in the supersaturated vapor around the drop in relation to the normal pressure of saturation P_s for the same temperature, if the drop just escapes shrinking by evaporation. An increase in P' for which the value has been calculated would cause the drop to grow. A drop smaller than that for which the value was calculated would disappear by evaporation; likewise a drop having a value of r larger would grow.

It is only when the drop is exceedingly small that the excess of P' over P_s is considerable. Kelvin calculated that for water vapor at 10°C. RT (which is treated as equal to PV) is 1.30×10^9 cgs units. The surface tension of water at the temperature above is 76 dynes per linear centimeter, and ρ is one gram per cubic centimeter. Then $\log_{10} \frac{P'}{P_s} = \frac{10.1}{D}$, where D is the diameter of the drop in millionths of a millimeter. The formula gives for drops of water the values shown in Table IX.

If Kelvin's formula is applied to naphtha drops at 10°C. it becomes $\log_{10} \frac{p'}{p_s} = \frac{1.2066}{D}$, where D is the diameter of the drop of naphtha in millionths of a millimeter.

When Kelvin's formula is rewritten to apply to the case of a

thin vertical film, such as that produced in the capillary space between two parallel plates, it becomes $\log_e \frac{p'}{p_s} = \frac{2S}{RT\rho(2d)}$, where d is the distance between the parallel plates.

If d is given in millionths of a millimeter, we have in the case of naphtha at 10°C. that $RT = 0.273 \times 10^9$ cgs. units. The surface tension of naphtha is $S = 28.3456$ and its density $\rho = 0.7466$. Therefore $\log_{10} \frac{p'}{p_s} = \frac{0.6033}{d}$. This formula expresses how large the pressure p' must be in the supersaturated vapor around the top of the wetting film, which has a radius of curvature d, in relation to the normal pressure of saturation P_s, for the same temperature, on the flat surface of the wetting film.

TABLE IX

DIAMETER OF DROP OF WATER IN MILLIONTHS OF A MILLIMETER	RATIO OF P'/P_s FOR WATER VAPOR	DIAMETER OF DROP OF NAPHTHA IN MILLIONTHS OF A MILLIMETER	RATIO OF P'/P_s FOR NAPHTHA VAPOR	RADIUS OF CURVATURE OF WETTING FILM OF NAPHTHA AGAINST A SINGLE PLATE IN MILLIONTHS OF MILLIMETER	RATIO OF P'/P_s FOR NAPHTHA VAPOR AT TOP OF WETTING FILM
100	1.02	100	1.014	100	1.028
50	1.05	50	1.028	50	1.060
10	1.26	10	1.149	10	1.320
5	1.59	5	1.320	5	1.743
2	3.2	4	1.415	4	2.003
1	10.2	3	1.589	3	2.525
		2	2.003	2	4.012
				1.5	6.370
		1	4.012	1	16.094

The ratio P'/P_s for different values of d given in Table IX below for naphtha are plotted along with Kelvin's values for water vapor in Fig. 1 Plate XXV.

For large radii of curvature the ratio P'/P_s for the three curves approaches unity, because then the surface is becoming flat. Chamberlain's value for the radius of molecular attraction, 1.5×10^{-7} cm., is now generally accepted. Chamberlain also determined the minimum thickness of a stable liquid film to be $4R$, or 6 millionths of a millimeter. At this value the curves

begin to separate rapidly and turn upward. When the radius of curvature equals the radius of molecular attraction, that is at 1.5 millionths of a millimeter, P'/P_s is large, and for a value slightly less than this a drop would evaporate in an explosive manner. Surface tension exists in a film 1.5 millionths of a millimeter in thickness. If it were possible to form a film of less than this thickness its surface tension would be weakened. In other words it would explode and become vapor, since its energy content is equal to the latent heat of vaporization. That this is the case is shown by the rapid increase in the ratio of P'/P_s in the region of 1.5 to 1 millionths of a millimeter.

Notwithstanding the large differences in surface tension and density between water and naphtha the curves in Fig. 1 Plate XXV show similar characteristics.

A steel straight edge 11 cm. long and 0.02 cm. thick, the upper edge of which had been sharpened to a razor edge, was placed in one path and parallel to the axis of the interferometer. The lower edge was submerged in naphtha. The appearance of the Fizeau bands is shown in Fig. 2 Plate XXVI. The curvature of the Fizeau bands is due to the evaporation of naphtha. The increasing distance between bands from bottom to top is due to the vapor density gradient which existed above the naphtha surface. The curvature of the bands from the flat side of the straight edge outward indicates the evaporation from the flat surface of the wetting film. The band just above the straight edge shows a kink, due to the high rate of evaporation from this sharp edge. The fact that the band is curved at all indicates very rapid evaporation, because the area of liquid at this curved surface is very small and a large amount of material would have to evaporate to show this curvature in a band above the sharp edge.

SUMMARY

1. Wetting films are formed by liquids containing two or more components of different vapor tensions.

2. Materials which produce no wetting film are found to be able to produce a wetting film when mixed if the liquids have different vapor tensions.

3. Saturation and unsaturation of the hydrocarbons play no part in the production of wetting films.

4. Low temperature combustion is not sufficient to contribute appreciably to the production of wetting films.

5. The variation of pseudo viscosity with temperature does not contribute appreciably to the production of wetting films.

6. The thickness of wetting films increases with rise in temperature, due to the increase in the true viscosity of the liquid mixture.

7. The thickness of wetting films increases with the age of the liquid mixture.

8. Wetting films have planes of cleavage which are exact multiples of the radius of molecular attraction.

9. Differences in surface tension due to localized evaporization play a primary rôle in the lifting of a wetting film.

10. The small radius of curvature at the top of a wetting film results in a high rate of evaporation, producing a region of high surface tension, and supplies the energy necessary to move the superficial layer upward. This drags with it some of the body of the liquid. The thickness of the upward moving layers depends on the true viscosity of the liquid mixture. Débris collects at the top of a liquid film in much the same manner as drift material on a beach.

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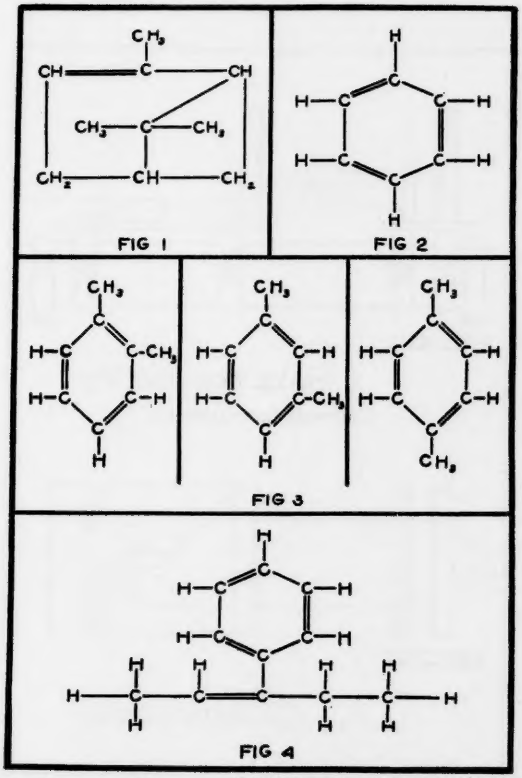
PLATE XXIII

STRUCTURAL FORMULAS

1. Pinene. 2. Benzene. 3. *ortho, meta,* and *para* Xylenes. 4. **alphaphenyl-betapentene.**



C. W. CHAMBERLAIN AND KENNETH LYLE WARREN STUDY OF PHENOMENON OF WETTING FILMS

PLATE XXIV

Universal Interferometer

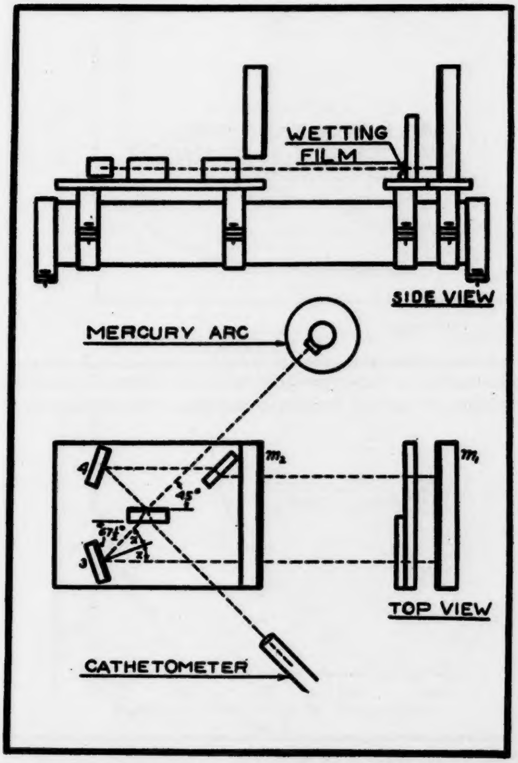


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PLATE XXV

Fig. 1. Relationship of vapor pressure ratios to radius of curvature.
Fig. 2. Variation of surface tension of naphtha with temperature.

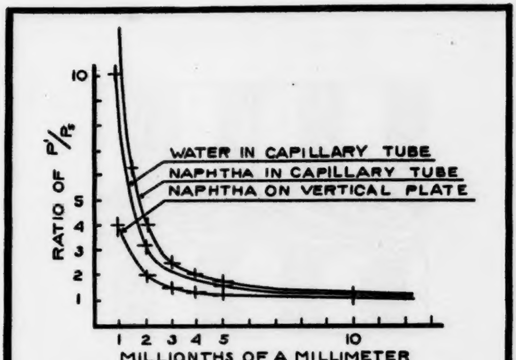

FIG 1

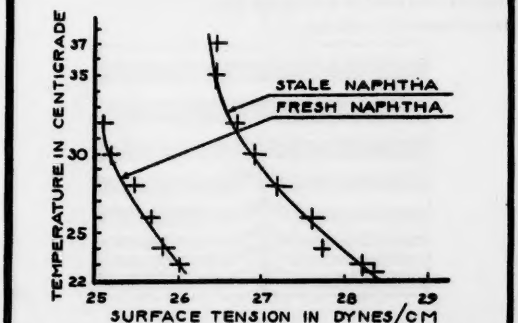

FIG 2

C. W. CHAMBERLAIN AND KENNETH LYLE WARREN — STUDY OF PHENOMENON OF WETTING FILMS

PLATE XXVI

Fig. 1. Motions observed in a wetting film.
Fig. 2. Fizeau bands in naphtha.

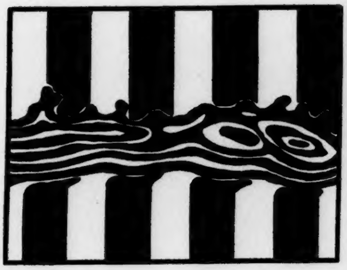

FIG 1

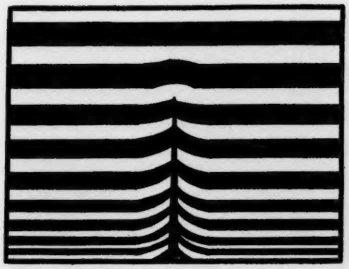

FIG 2

C. W. CHAMBERLAIN AND KENNETH LYLE WARREN STUDY OF PHENOMENON OF WETTING FILMS

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